WIRED
UK EDITION

MEETS Stephen Hawking

PLUS WHAT YOU MISSED AT WIRED2014

EXCLUSIVE INTERVIEW

+FRAMESTORE'S SFX SECRETS

+ROBOTS ATE YOUR JOB (BUT YOU'LL BE FINE)

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+HOW TO GROW LIKE GOPRO

IDEAS | TECHNOLOGY | DESIGN | BUSINESS

Official fuel economy figures for the BMW i8: Weighted combined cycle: mpg 134.5 (2.1 l/100 km), CO_2 emissions 49 g/km, power (weighted combined cycle) 11.9 kWh, customer-orientated total range up to 373 miles. Maximum electric range value 23 miles, common climatic conditions, route characteristics and preconditioning. The BMW i8 is a plug in hybrid electric vehicle that requires mains electricity for charging.

output (engine) 170/231 kW/hp, power output (electric motor) 96/131 kW/hp, total average energy consumption per 62 miles/100 km average electric range value (e-Drive only) up to 23 miles. Figures may vary depending on different factors, including but not limited to individual driving style,

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088

Fashion for every body

Designer Brooke Roberts uses MRI scans to make science-inspired clothes

073

WIRED2014

From tech superstars to the next generation of disrupters, here's what happened at WIRED2104

112

Stephen Hawking

WIRED talks to the greatest living physicist about science, speech and the Universe in our exclusive special feature

126

Your job automated

Will the inexorable logic of AI render us obsolete, or will our fuzzy fallibility – our humanness – save us?

134

The image engineers

How the London-based visual-effects experts Framestore resurrected a dead actor and created outer space on Earth

144

War of the worlds

Two teams of astronomers claim to have found the first Earth-like planet, Gliese 667Cc – but which one is right?

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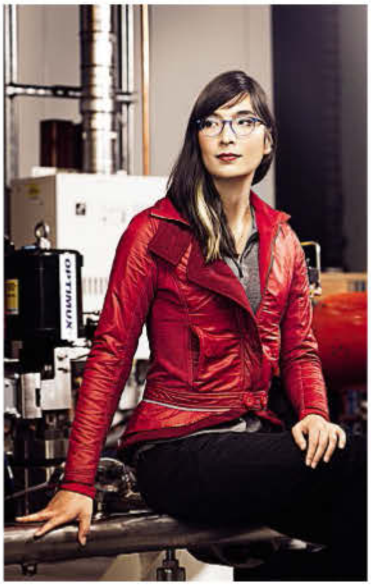


019

START
GoPro's unique POV
Nick Woodman, founder of GoPro, explains his company's similarities to Apple and where he's taking it next

026

START
Green machine
Danielle Fong has created a bold new business out of clean-energy storage – in fact, it's a breath of fresh air

042

START
Social constructs
A Dutch designer has built mobile homes and shelters for orphaned Inuit children in Greenland, by putting them on sledges

Clockwise from top-left: Energy specialist Danielle Fong; beekeeper Jack Chapman; Framestore's Mike Woods; *Situation Room*, by Jana Winderen; how to light a fire with a water bottle; super-detailed insects; mirrors at Sydney's One Central Park

054

GEAR
Buzz feeders
We rate three of the best beekeeping kits to see which is most suited for year-round cultivation of the sweet stuff

065

IDEAS BANK
Brain food and provocations
Featuring Charles Spence, Tim Leberecht, Walter Isaacson, Eldar Shafir and Marina Gorbis

095

PLAY
Icicle works
Beijing-based architects MAD find the perfect form to create its new buildings – in the shape of frozen liquids

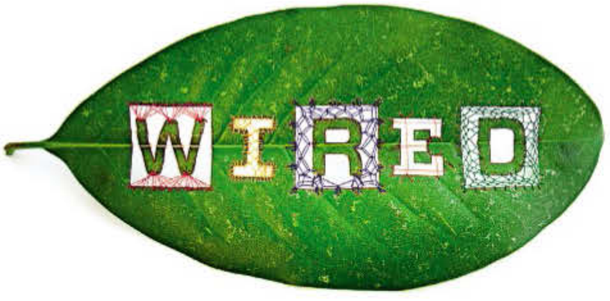
098

PLAY
Aerial unit
How drones helped David Attenborough reach new heights for his latest Sky 1 series, *Conquest of the Skies*

105

HOW TO
Life enhancement
Light a fire with a water bottle; make a bleach-patterned T-shirt; fold an origami envelope; massage statistics

PHOTOGRAPHY: CODY PICKENS; SUN LEE; FRAMESTORE; MIGUEL DE GUZMÁN; LEVON BISS. ILLUSTRATION: LEO ESPINOSA



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OFF-PAGE

WIRED2014

"Thanks #WIRED14 , meet crazy interesting people, finally get my genome screened and became a Google glasshole – all on the same day"

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PHOTOGRAPHY: PETER BEAVIS; JAMES DAY

"1,000MPH? THAT'S THREE FOOTBALL PITCHES EVERY SECOND. MAD"

@SURAJ_LFC ON 12.14'S BLOODHOUND STORY

FEEDBACK

"Ridiculous (Derailing a myth, 11.14). It cost me £158 to buy a travel-anytime first-class ticket from London to Bristol – a trip that took two hours. In the Netherlands a ticket from Amsterdam to Groningen – a trip of two-and-a-half hours – costs €42 travel-anytime first class." **Richard Kastelein, via wired.co.uk**

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WIRED – remember when you said Wonga was the next best thing because of its algorithms (Payday loan rates capped, wired.co.uk)? I do, but we all make mistakes... **Martin Robertson, via wired.co.uk**

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Swift exit

"Taylor Swift is little more than a pawn in the game being played by the traditional music industry as it struggles for survival (Spotify defends its model following Taylor Swift's exit, wired.co.uk). If all the tracks on her album were equally in demand, they would sell just as much individually and the industry wouldn't have anything to worry about. Perhaps Swift cares too much about album sales. Perhaps the industry isn't passing on its Spotify revenue. Perhaps this is a misguided ideological move." **Tim Acheson, via wired.co.uk**

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Social intervention

"I welcomed this 'invasion' (Samaritans pulls Twitter suicide-prevention app, wired.co.uk): 40 years ago there was no such help available. Social media is here to stay. If you don't want your feelings to be known, don't use it. Find a private line of communication. But for others, for whom this could have been life-changing, embrace what's on offer." **Pat Seymour via wired.co.uk**

WIRED2014

Robots are awesome!

Quadriplegic Robots and Cake! founder Stuart Turner (*left*) after flying a drone over the WIRED2014 audience via a telepresence robot from his Manchester home

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▲ MAKING WIRED / SHOOTING A STAR

Photographer Marco Grob caught up with Stephen Hawking in Lanzarote, to shoot him for our cover and special feature: "I have always held Professor Hawking in high regard. We should not forget that people like him are risk-takers, individuals whose thoughts and theories directly confront and dispute many of any human society's most traditional and fundamental ideologies."

Marco Grob: "If I could ask Stephen Hawking one question, it would have to be 'How do you see the world?' I missed my chance, unfortunately. Because he ran over my foot with his wheelchair."

▼ MAKING WIRED / EXTREME PHOTOGRAPHY

Dan Burn-Forti had a speedy photo-shoot with Nick Woodman, founder of GoPro: "Being a fan of the GoPro, I was looking forward to meeting its inventor. The shoot was pretty quick – he had to jump into his private jet to fly off to his next meeting straight after. But Nick was more than happy to do as I asked, especially when he saw my cotton-wool clouds. I know, so lifelike, eh?"

DAVID BAKER

Baker, the editor of *The WIRED World in 2015* (out now, £6.99) and a teacher at the School of Life, profiles Framestore – the UK SFX firm that supplies magic to everything from chocolate ads to Harry Potter. "'Real' is a word that comes up a lot in conversations at Framestore," he says. "But making the unreal real is its speciality."

MARINA GORBIS

In Ideas Bank, Gorbis, executive director at the Palo Alto-based Institute for the Future, writes about the impact of "extreme learners" on education. "What 'extreme learners' are doing today on the fringes will be the norm in ten years," she says. "This necessitates a much grander rethink of institutions than attempted so far."

SIGNAL NOISE

Hem Patel, Bob Wilson and Christian Thümer of information design agency Signal Noise create the Infoporn this month, rating how "good" countries are. "We tried to compromise between granularity and the bigger picture," says Thümer. "I'm half-Danish," says Wilson. "I was surprised at Denmark's [low] ranking."

ELDAR SHAFIR

The co-author of *Scarcity: The True Cost of Not Having Enough* writes in Ideas Bank about the mental cost of being poor. "The human cognitive system has limited capacity," he says. "Focusing on the problems that come with having too little grabs substantial mental resources and leaves less mind for everything else."

EMILY PECK

So thorough is this month's Test of top beehives, it took 12 months to write. "It was a wet year, but we still got a bumper of crop of honey, which was really satisfying," says Peck. "Beekeeping has become a bit of a virtuous, feel-good hobby, but it's also quite scientific. And bees are beautiful – though I'll stick with my goldfish."

PHOTOGRAPHY: MARCO GROB; DAN BURN-FORTI

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FROM THE EDITOR

This month WIRED travels further than ever before – to the outer limits of the Universe. Strap yourself in for an epic voyage of discovery into the innermost workings of Stephen Hawking's amazingly agile mind. Sit tight as we take you into a stellar fight among astronomers about who discovered what could be the first Earth-like planet in outer space. And marvel as we go inside Framestore, the amazing London special-effects house whose visuals recently won an Oscar for its work on the movie *Gravity*.

You can see Eddie Redmayne playing Stephen Hawking in cinemas this month – but there's nothing like the thrill of meeting the man himself. Our science editor, João Medeiros, was excited when the call came to visit the professor in Tenerife in October. Hawking had to travel there by boat, as his health precludes flying, and as well as lecturing he gave WIRED time to explore his latest thinking about the origins of the Universe – and why he would like to play a *James Bond* baddie. As one of Britain's most celebrated living scientists, Hawking has a rare ability to transcend the complexity of physics to communicate big ideas in an accessible way. His answers to WIRED's questions will help you understand some of the biggest unresolved mysteries of space science. And as for the innovations that are allowing Hawking to communicate despite his physical constraints, we were fascinated to learn how far he and Intel had come in designing ways for him to speak and write.

If you missed WIRED2014, our flagship two-day event in October, and our Next Generation event to inspire teenagers, you can read about some of the key speakers in a special section in these pages. Catch the videos of the talks too, at wired.co.uk/wired-2014. This year, we brought together the inaugural WIRED Innovation Fellows, a dozen emerging stars in fields from bio-science to motorcar manufacture, who we invited to London to share their stories on our stage. We're just launching our search for 2015's WIRED Innovation Fellows, so spread the word: we don't care how old the applicants are, where in the world they are based, whatever their background. All we're looking for are exceptional people who are changing the world in their own way, and who have already achieved a degree of success. This year, we're also partnering with The Space to award £100,000 to three digital artists who will create an artwork as part of their fellowship. See wired.co.uk/fellows for more.

Former Hailo CEO Jay Bregman was one of more than 50 speakers to appear at WIRED2014

PHOTOGRAPHY: JAMES DAY

David Rowan

David Rowan

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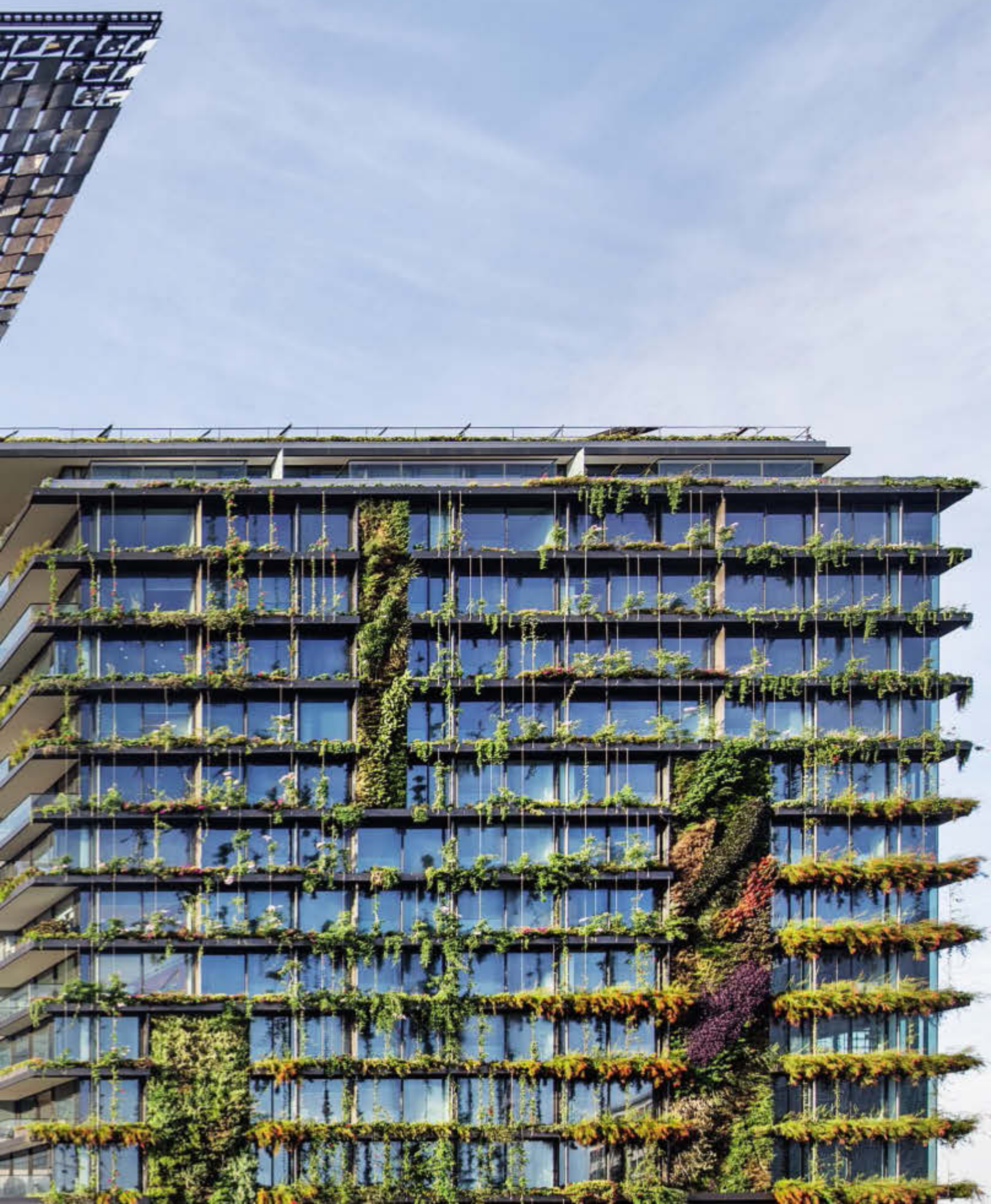
START



Vertical Sun-trap

Despite standing 33 storeys tall, Sydney's One Central Park barely casts a shadow. On the roof of the block's lower tower are 40 heliostats – motorised mirrors that track the Sun's movement and redirect its light up to a reflective frame cantilevered from the taller tower. "These 320 fixed mirrors then reflect the light in all directions," explains the project architect for the east tower, Mark Giles of Sydney-based PTW architects, who collaborated with Frenchman Jean Nouvel. "Half of it comes down to the park south of the building, providing sunlight to an area that would have been in shadow. The other half is directed through an atrium to the building below."

The second reflection serves an important purpose in de-intensifying the Sun's rays. "The double bounce of light, from the heliostat to the reflective frame, gives the effect of dappled sunlight, as though it were filtered through a tree canopy," explains Giles.

One Central Park is further camouflaged by a living skin of 180,000 plants that comprise the world's tallest vertical garden and provides natural shade to the apartments. Around 350 species were used to cater for the different climates, including the almost alpine environment at 100m up. "A lot of Sydney is densely urban," says Giles. "The idea with this planting is to give Central Park residents a green link to their own garden, whether they're at level five or level 30." **Kathryn Nave**

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Tablet extra!
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GOPRO'S UNIQUE POV

GOPRO FOUNDER NICK WOODMAN is on a high. In June, 12 years after strapping a disposable camera to his wrist in Indonesia, his company IPO'ed at a value of almost $3 billion (£1.86bn). "The GoPro you know today is built on $265,000," the animated Californian tells WIRED. In 2002, Woodman was surfing his way round the globe, recovering from the failure of his first company, gaming and marketing platform funBug. Six months later he left Indonesia with an idea for a small, robust video camera for capturing first-person experiences, and 600 beaded shell belts that he would sell to make up the startup costs (along with a $235,000 loan from his parents). "It is one of the things we are most proud of. You don't have to raise millions of dollars to be successful, you just have to work on something you are passionate about," he says.

GoPros have been strapped to countless extreme-sports enthusiasts, including Felix Baumgartner during his space jump – as well as to eagles soaring over remote Mongolian terrains, a pelican learning to fly, a kid's chest on his first day of school, frat boys on spring break and plenty of expectant fathers in the delivery room. It's because of this exponential diversity that GoPro shows no sign of slowing. Here, Woodman talks to WIRED about launching a sharing platform for GoPro footage, competing with newcomers and what he's learned from failure. **Liat Clark** *gopro.com*

WIRED: How do you convince people that GoPro isn't just for extreme sports?
Nick Woodman: Now I'm the father of three young boys, I find myself using GoPro to film them more than anything – trips to the amusement park, the beach, the pool – just chasing them around as they grow. That's leading to ideas for new accessories to help the family capture its lifestyle and go from the two hours of footage to the two minutes they will actually want to watch and share.

PHOTOGRAPHY: DAN BURN-FORTI

How will you deliver that?
You could think of GoPro as an iPod-like phenomenon that is yet to release its iTunes. We are developing the app that makes it easy for you to offload content. So when you are charging, that content goes to the cloud and becomes accessible to any connected device running the app. Upon watching it [on your mobile] it is important you have easy edit tools to turn that raw footage into something shareable – because at that moment, that is when you are going to be most inclined to do something. You will share ten, 20, 50 times as much content a year as you do today, because it is so difficult today.

GoPro is now in some BMWs. Where else would you like it installed?
The world shows you how it wants to use it. We can try to influence new markets by positioning our products in a certain way, but the truth is that humans are smart [and will] use it in any way they see fit.

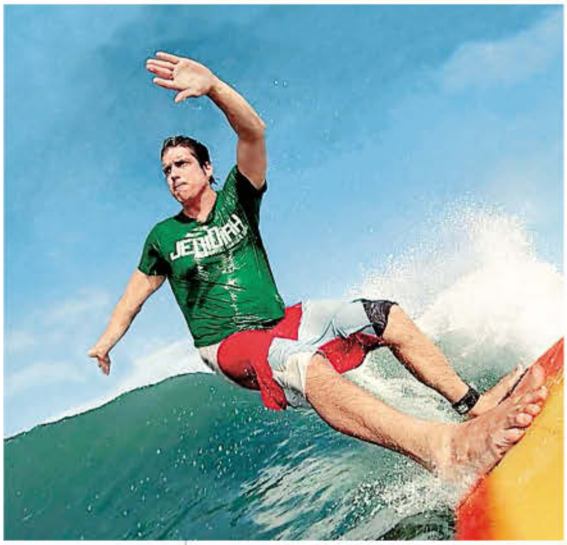
My doctor replaced my anterior cruciate ligament three months ago and decided to wear a GoPro while doing it, because he wanted to document his technique. In France, a hip replacement was captured using two GoPros in a stereoscopic 3D arrangement. Students can watch the surgery using a virtual reality headset. It is phenomenal, and we had nothing to do with that.

Is there a danger that we're all too concerned with capturing the moment, rather than just living it?
I experienced just that filming the birth of my sons – and the benefit of GoPro. I was able to wear my camera during the birth of each but I never held the camera. My experience of being with my wife and watching my three boys being born was never interrupted by a camera or by an LCD display. I was able to be totally present and I forgot that the camera was running. So it didn't interrupt my experience at all. That speaks to our success in developing what we think of as an invisible camera that is so convenient and easy to use, that you forget you are even using it.

Do you have any GoPro tips?
Experiment, capture lots of different perspectives of whatever it is you are doing and be bold. It's a GoPro: go for it. This sucker is meant to take a beating.

How will you compete with the newcomers to the market?
We've amassed a customer base of millions of people who are capturing and sharing their lives with GoPro, and that's really the secret to our success. If that's what makes GoPro so successful, then to compete with GoPro by definition you also need millions of people capturing and sharing their lives and attributing that content to your brand.

What did you learn from the failure of your previous startup, funBug?
When I was 22, I realised I wanted to be an inventor. I knew I would have to work very hard and would probably fail a few times, so I gave myself until the age of 30 to succeed. It is a good thing I did that because if I hadn't I might not have tried again – I was pretty devastated. I lost $4 million of other people's money and people believed in me... I wasn't sure if I was cut out for it. After that, I found myself with four years left on the clock and figured, hey, I will regret it for the rest of my life if I don't try again.



GOPRO IMAGE: NICK WOODMAN

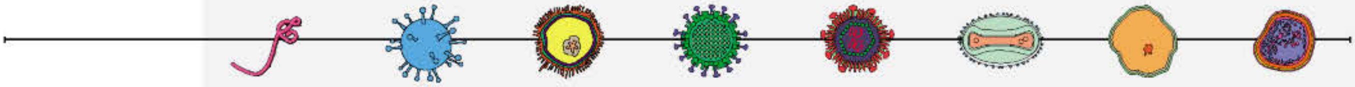
Woodman (*above*) developed the GoPro using a video camera, surfboard leashes and rubber bands

What did you do differently the second time around?
I was going to bootstrap it the next time around because I was fearful of taking anybody else's money. I promised myself that whatever I did next, it would be something I was personally passionate about because there were aspects about funBug where it was just business. It seems obvious, right? Just focus on what you are passionate about and you will do the best job, because it is something you really care about.

SPREAD VS DEAD

At the time of writing, the Ebola outbreak had infected nearly 10,000 people, killing about half of them. The epidemic leaked out of West Africa into the US in October, infecting two nurses who contracted the virus while caring for a Liberian patient in Texas. So does this mean we are at the cusp of a global contagion? Health officials in the US and UK say no. Their reason: Ebola isn't as contagious as it is deadly. WIRED charts the contagiousness-versus-biological-hazard reproductive ratios of eight viruses, based on their R0 (basic reproductive rate). **MV**

	EBOLA	HEPATITIS C	FLU	SARS	HIV	SMALLPOX	MUMPS	MEASLES
Contagiousness	2	2	3	4	4	7	10	18
Biological hazard	4	4	3	3	2	2	2	2



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Headspace cofounder
Andy Puddicombe in
Cambridge Circus, London

PHOTOGRAPHY: GARY SALTER

ZEN ON YOUR SMARTPHONE

Andy Puddicombe's mindfulness app has won the attention of Olympians, doctors and Tibetan monks

WHEN FORMER MONK ANDY PUDDICOMBE ANNOUNCED his idea to teach mindfulness with an app, his Tibetan Buddhist teacher was horrified. "I felt very unsure as well," says Puddicombe, cofounder of LA-based Headspace. "In the Tibetan tradition, there's an unbroken oral lineage from teacher to student of almost 900 years. There's a risk in scaling something like this, taking it out of its environment, diluting it."

Puddicombe took the plunge and cofounded Headspace in 2010 with Rich Pierson, a former employee of creative agency BBH. The app's content ranges from ten-minute mindfulness sessions to advanced modules that tackle problems such as poor sleep and stress. The app has now been downloaded by more than a million iOS and Android users in 150 countries.

Independent scientific evidence validates the benefits of mindfulness to alleviate depression, aid cognition and strengthen cardiovascular health. There are currently 38 ongoing and planned academic studies with Headspace in conjunction with establishments such as University College London and Yale: in one study related to stress in the workplace, clinicians observed a significant reduction in participants' systolic blood pressure after eight weeks of using the app. "We have a clinical trial with St Bartholomew's looking at chronic pelvic pain," says David Cox, Headspace's chief medical officer and a lecturer at the Imperial College School of Medicine. "If successful, it could lead to the app being prescribed by NHS doctors for chronic pain."

Headspace was created by Bristol-born Puddicombe who previously worked with physicians in London. "I started to experiment to see what worked and what didn't," says Puddicombe. "Meditation is essentially a neurological skill with broad applications. We can wrap it around many different ideas and philosophies, but ultimately it's about being present."

This month, Headspace will start testing a version for kids in schools in Seattle, LA and Chicago. It is also developing tailored programmes for parents, pregnant women and athletes – an Olympic team is using it in its preparation for 2016. And the app has come full circle: "There's a Tibetan monastery in Nepal," says Puddicombe. "Before they begin their training, they are told to do ten days of *Headspace*." **JM** *headspace.com*

FIND SOMETHING SPECIAL THIS CHRISTMAS

This winter, let Canon help you capture your most memorable stories with cashback offers and FREE accessories on selected products*. Step into DSLR photography and let your creativity grow with the Canon EOS 700D. From shooting in low light or from a distance, with over 70 lenses in the range you can capture all the beautiful and unpredictable stories you find. Whether it's a present for someone or you're treating yourself, Canon has something special for everyone.

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Available on selected European products purchased between 29.10.2014 and 21.01.2015 from UK retailers.

THIS GRAPH IS ONE WAY TO DETERMINE which nations contribute most to the good of the human race. Simon Anholt, an independent government-policy adviser, compiled a ranking called the Good Country Index. "Ireland came out on top," says Anholt. "It gets very few low scores overall: it didn't contribute any troops to Afghanistan in 2010, when the index was calculated, and therefore, any deaths. It gives a lot to charity, has low population growth and generates almost no refugees." Other countries in the top ten included New Zealand, Finland and the UK.

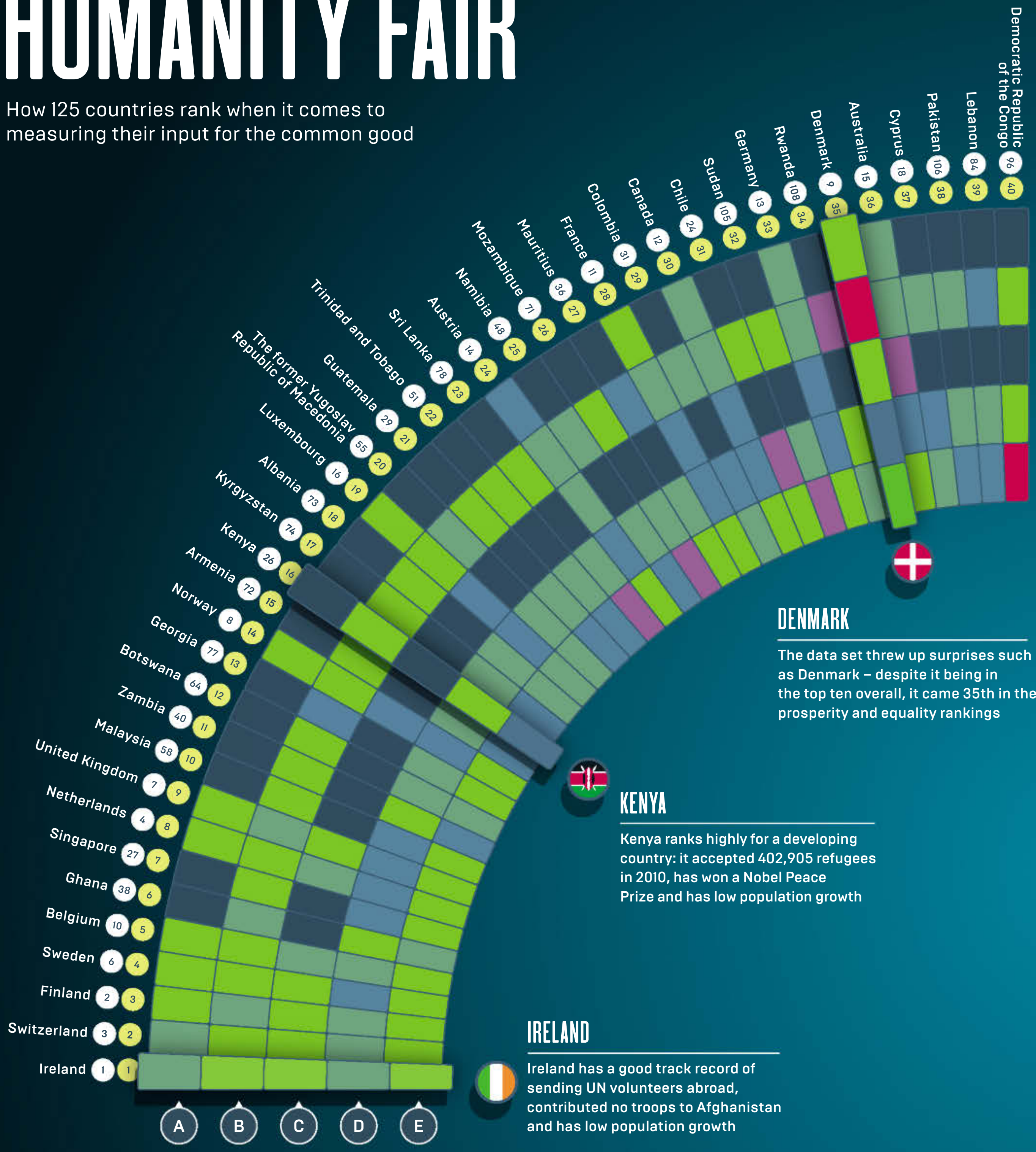
"Many international surveys out there measure the performance of countries, but do so in isolation from each other," says Anholt. "In a connected world where most problems are global problems, it makes more sense to look at the external impact of countries and measure their impact on the rest of humanity."

Anholt spent two years selecting 35 reliable data sets compiled by the United Nations and other international agencies that measure the external impact of countries across seven categories such as Science and Technology, World Order, Planet and Climate, Health and Wellbeing, and Prosperity and Equality (*shown below*). He then divided the data with each country's GDP, so richer ones wouldn't come out on top by default.

"The next phase is not about measurement, but about action," he says. "The Index should help ordinary citizens around the world to persuade their governments to think more internationally, and stop being selfish. That's the aim of the project." **MV** *goodcountry.org*

HUMANITY FAIR

How 125 countries rank when it comes to measuring their input for the common good



DENMARK

The data set threw up surprises such as Denmark – despite it being in the top ten overall, it came 35th in the prosperity and equality rankings

KENYA

Kenya ranks highly for a developing country: it accepted 402,905 refugees in 2010, has won a Nobel Peace Prize and has low population growth

IRELAND

Ireland has a good track record of sending UN volunteers abroad, contributed no troops to Afghanistan and has low population growth

- 🟩 Far above average
- 🟩 Above average
- 🟦 Average
- 🟪 Below average
- 🟥 Far below average
- ⬛ No data

**Good Country rank**
Overall index rank

**Prosperity & equality**
Overall rank by prosperity and equality contributions

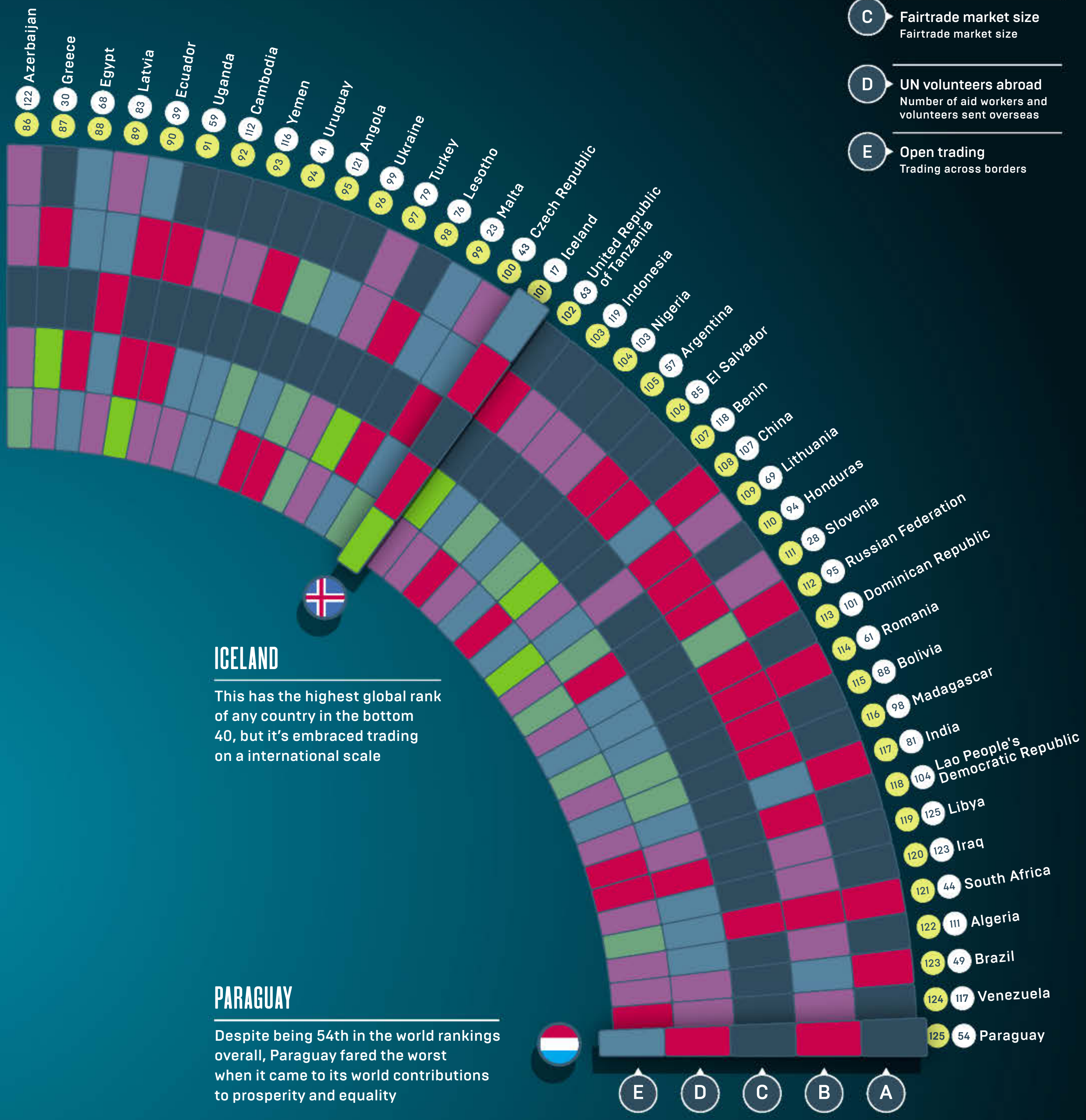
A **Development assistance**
Development co-operation contributions (aid)

B **FDI outflows**
Investment into foreign countries (as % of GDP)

C **Fairtrade market size**
Fairtrade market size

D **UN volunteers abroad**
Number of aid workers and volunteers sent overseas

E **Open trading**
Trading across borders



86	122	Azerbaijan
87	30	Greece
88	68	Egypt
89	83	Latvia
90	39	Ecuador
91	59	Uganda
92	112	Cambodia
93	116	Yemen
94	41	Uruguay
95	121	Angola
96	99	Ukraine
97	79	Turkey
98	76	Lesotho
99	23	Malta
100	43	Czech Republic
101	17	Iceland
102	63	United Republic of Tanzania
103	119	Indonesia
104	103	Nigeria
105	57	Argentina
106	85	El Salvador
107	118	Benin
108	107	China
109	69	Lithuania
110	94	Honduras
111	28	Slovenia
112	95	Russian Federation
113	101	Dominican Republic
114	61	Romania
115	88	Bolivia
116	98	Madagascar
117	81	India
118	104	Lao People's Democratic Republic
119	125	Libya
120	123	Iraq
121	44	South Africa
122	111	Algeria
123	49	Brazil
124	117	Venezuela
125	54	Paraguay

ICELAND

This has the highest global rank of any country in the bottom 40, but it's embraced trading on a international scale

PARAGUAY

Despite being 54th in the world rankings overall, Paraguay fared the worst when it came to its world contributions to prosperity and equality

INFOGRAPHIC: SIGNAL NOISE

Above: Danielle Fong on the latest RAES. It can power a medium-sized commercial building

PHOTOGRAPHY: CODY PICKENS

GREEN MACHINE

Think clean energy is a load of hot air? Danielle Fong couldn't agree more – in fact, she's made it her business

DANIELLE FONG WANTS TO REINVENT the power grid – using air. "We are burning through our carbon budget and temperatures are rising," says the 27-year-old founder of Berkeley-based LightSail Energy. Her solution – power stored in compressed air tanks.

"Air is limitless, inexpensive and lasts a long time compared to batteries," says Fong. Such a device could be plugged into solar and wind farms, where it would hoard and dispatch energy when demand is higher. "The problem with renewables is their unreliability," she says. "They fluctuate with the weather and time of day." LightSail aims to smooth that out – over the next two years, LightSail's Regenerative Air Energy Storage (RAES) units will be deployed at a half-megawatt scale in California, Hawaii, Canada and the Caribbean, before 20MW units are rolled out in 2017.

Fong, who went to Dalhousie University in Novia Scotia at the age of 12, had worked on nuclear fusion research during her PhD at Princeton, but felt it was moving too slowly. "Where is our energy going to come from? This is an enormously urgent challenge, and there are huge, missing technologies," she says. "It seemed all the money was in Silicon Valley, so I dropped out and moved there to pitch my idea," she says. It worked: so far she has raised $58 million (£36m) from investors including Vinod Khosla, Total Energy, Bill Gates and Peter Thiel.

The process uses electricity to mechanically compress air and store it in a tank. To get energy back, expand the compressed air, which drives a generator to produce AC power. "When you compress air, it gets so hot that you could not store it – it's 2,000°C at 200 atmospheres," Fong explains. "So we cool it during compression by spraying water into the air and capturing the heat." The warm water is sprayed back in when the air is being expanded. This doubles the current efficiency of this process. "The energy space is a trillion-dollar industry in the making," she says. "So if you think you have an idea for an energy technology, please build it. It could really transform the world." **MV** *lightsail.com*

The Wireless HiFi System
Sonos Your Home
SONOS

A tour of Flatland

What the book about life as a square can teach us

MATHEMATICIAN IAN STEWART wants us to see what he sees: snowflakes in fractional dimensions, hypercubes in 4D and 11-dimensional superstrings. So when the University of Warwick professor and author writes about these geometries, he relies on an analogy – a way for us blockheads to understand realities above, below and in between our three dimensions. His guide is a little mathematical fantasy he read over half a century ago: the cult classic, *Flatland*.

Written in the early 1880s by Edwin A Abbott, the story follows A Square, a regular quadrilateral who lives on a 2D plane. He can't conceive of depth, but his perspective expands when a sphere visits him from 3D Spaceland. Though Square can't experience all three of the sphere's dimensions, he can see it in cross-section as a circle of various sizes. By describing what it's like for a flat object to imagine a solid one, Stewart can help us imagine a 4D object. A 4D sphere (called a glome) might appear to us as expanding and contracting spherical cross-sections. "Starting with *Flatland*'s point of view," he says, "you find a way in." Stewart considers *Flatland* one of the earliest works of popular science, a genre he's been writing in for decades (his latest book came out in October). In addition to an annotated *Flatland* and its follow-up (*Flatterland*), he has collaborated on four books about the science of Terry Pratchett's Discworld, in which wizards ponder the strange technology of Earth.

In Flatland and Discworld, the act of removing yourself from your own reality allows you to understand it. And Stewart wants his readers to push that concept as far as they can. "How does the fourth dimension relate to the 11th?" Stewart asks. "We can crank up the analogy." Whatever you say, Professor – we'll keep an eye out for *Stringland*. **Jason Kehe**

ILLUSTRATION: VALERO DOVAL

DEEP-SEA VISITORS

What lies beneath? That's the question being asked by British Antarctic Survey researchers. They have developed a camera system to survey the polar seabed, near Adelaide Island, within the Antarctic Peninsula. Their goal: to explore the biodiversity of the Antarctic ocean floor at depths of up to 1,000m. With a custom-built winch system and fibre-optic link, Peter Enderlein and his colleagues will be able to lower their Prosilica GiGE high-resolution camera and Aqua Vision Bowtech LED-2400 lights to glimpse the relatively unexplored Antarctic seabed. "You get areas where you suddenly find a huge number of different species in a very concentrated space," says Enderlein. "It would be exciting if we hit one of these." **Chris Baraniuk** *antarctica.ac.uk*

Sonos Your Home
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The Wireless HiFi System

Pre-orders of the LEAP have reached 7,700 units before production has even started

Giant steps for LEAP

THIS ENGINE COULD BE POWERING YOUR business trips by 2016. Called the LEAP, it boasts laser-printed fuel nozzles, heat-resistant ceramic composites and woven carbon-fibre fan blades: three first-time material innovations designed to cut fuel consumption.

"It really is a radical jump in aviation," says Gareth Richards, LEAP programme manager at GE, which builds the engine's core. Given that fuel accounts for one third of an airline's operating costs, its 15 per cent saving could make the difference between profit and loss, says Richards.

LEAP's fan blades are made by weaving carbon-fibre strands into a solid, allowing for shapes that weren't possible with titanium. "We use specialised looms to weave them," says Richards. Blades are much lighter, although just as strong, and in the engine's hottest parts many components are made from GE-engineered ceramic mixed with silicon carbon fibres. These are two-thirds lighter, twice as strong and can withstand 20 per cent higher temperatures. The design also reduces CO_2 and NO_x emissions by 50 per cent.

3D printing has been used in aviation for years, but the LEAP uses additive techniques to produce an unusually sophisticated and critical part: fuel nozzles. These spray fuel into the engine and were previously composed of 22 pieces; here, lasers fuse 20-micron-thick layers of metal powder into shape, and the nozzles can be designed as a single, solid piece – making them 25 per cent lighter and five times more durable. "We have plans to expand its use across the engine – for much bigger parts," says Richards.

Preorders worth $78 billion (£43 billion) to date have been placed by 20 countries. The engines, being developed by CFM (a 50-50 collaboration between GE and France's aircraft and rocket engineer manufacturer Snecma), go into production next year and are scheduled to take to the skies in the Airbus A320neo from 2016. **Jeremy Kingsley** *cfmaeroengines.com*

WIRED	TIRED	EXPIRED
Somebody	***Whisper***	Facebook
Koomey's law	Metcalfe's law	**Moore's law**
Infinity Stones	**Elven rings**	Maltese Falcon
Hormone economy	Attention economy	**Click economy**

The Wireless HiFi System
SONOS
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APPS OF THE MONTH

iOS 8-optimised options

OMNIFOCUS 2

▲
WIRED

OmniFocus 2 is a highly regarded to-do manager and project organiser. Its major update for iOS 8 and iPhone 6 takes advantage of Siri, notification widgets and extensions for other apps. *iOS, £13.99 omnigroup.com/omnifocus*

PCALC

Love mathematics? This app brings advanced scientific-calculator action to the iPhone 6 and new iPads. iOS 8 enhancements include quick-calculator functionality in the form of an interactive widget. *iOS, £6.99* pcalc.com

SWYPE

Adding new keyboards is one of iOS 8's best features and one of the greatest of them all is the *Swype* keyboard from Nuance. It does away with tapping in favour of gesture-based, one-fingered swiping to form words. *iOS, Android, 69p swype.com*

1PASSWORD

A major update in the guts of iOS 8 is the support for apps to talk to each other. *1Password* is an essential password manager if security is key. It syncs to your Mac and other devices for consistency. *iOS, Android, free agilebits.com*

MANUAL CAM

We use this app when reviewing iPhones as it allows us to manually set their exposure, ISO, focus and more. It's a simple app that provides professional functionality – not to mention much creative joy. *iOS, £1.49 lofopi.com*

GOAT SIMULATOR

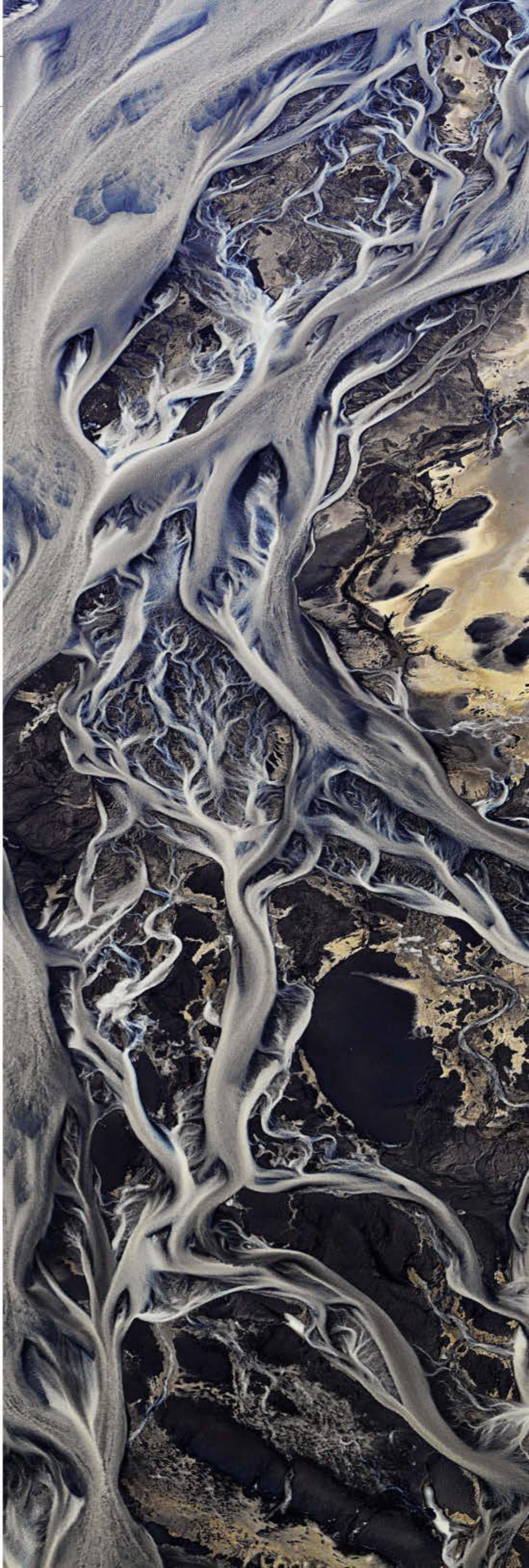
▲
WEIRD

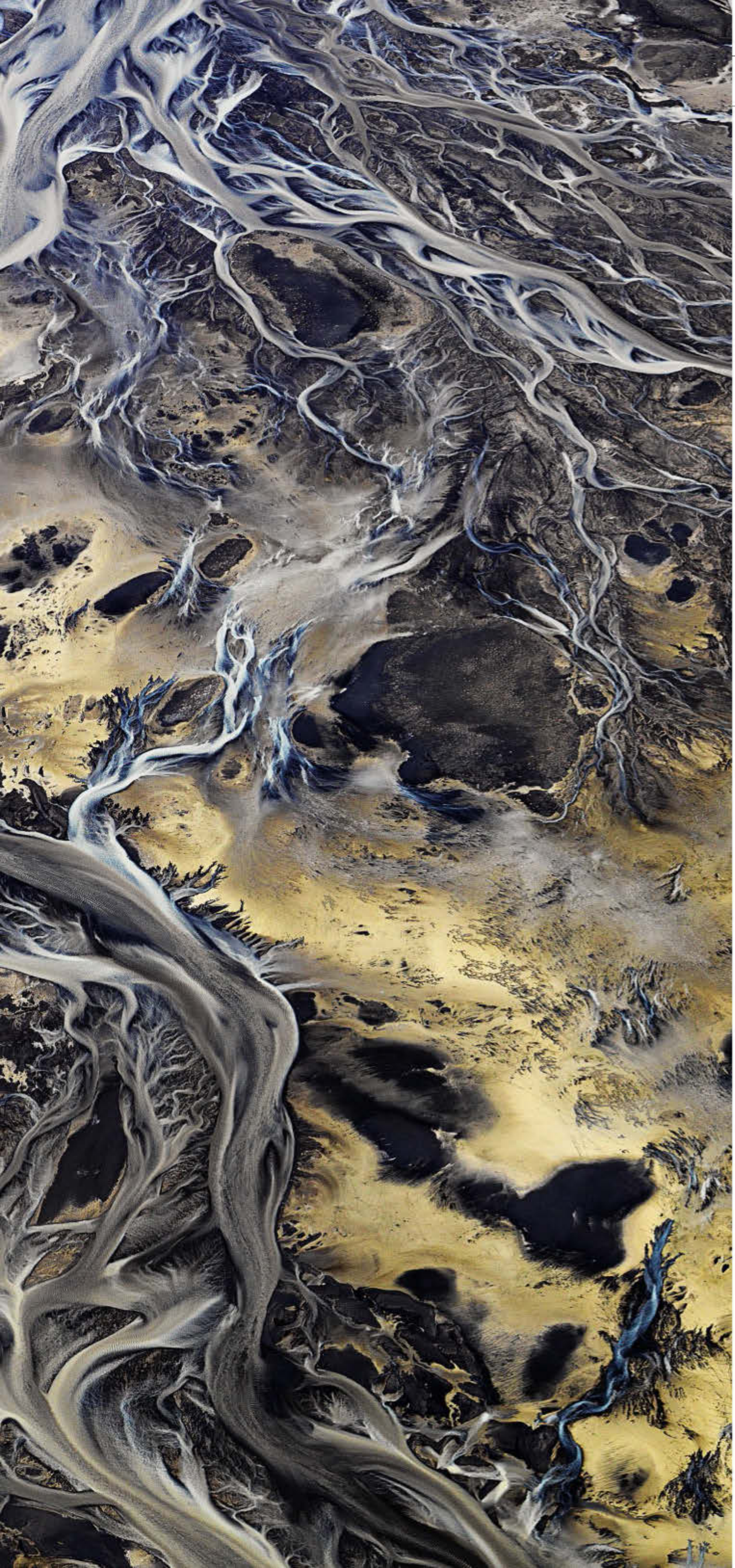
We had to include this as it was genuinely the first game WIRED tested on the iPhone 6 Plus. Its premise: you are a goat, wreaking havoc around a real-world environment. It's as ridiculous as it is hilarious. *iOS, Android £2.99 goat-simulator.com* Nate Lanxon

EBB AND GO

This is Iceland's Fúlakvisl river, whose delta channels volcanic soil and golden iron oxide. You'd better take a look while you can, as it's disappearing fast. The Fúlakvisl receives its water from the Langjökull glacier, Iceland's second largest, which has been losing mass for almost two decades due to global warming. "It's been losing more than 1.5 metres every year since 1996", says Finnur Pálsson, a glaciologist from the Institute of Earth Sciences at the University of Iceland.

Pálsson and other researchers have used predictive models to show that by the end of the century, the glacier could be down to 20 per cent of its mass. "These glaciers sustain life in the Arctic," says Hans Strand, who took the photo. "They provide a constant water flow – and when that disappears, of course, life also disappears."
Emma Bryce
hansstrand.com





Visionary footwear from the media lab

Inventor Anirudh Sharma wants to make computer interfaces more physical. Among the 33-year-old's creations: shoes that help the visually impaired navigate using haptic feedback and Google Maps. "It started as a tinkering project," says Sharma, a research assistant at the MIT Media Lab. "We used very simple Nokia phones with a basic microprocessor in the shoe." That was in 2011: the finished Lechal shoes, which pair with an Android smartphone and use Google Maps to navigate, retail for $150 (£95).

Sharma has also created the Glassified, a concept ruler for designers and architects with a transparent LCD display (it can calculate measurements and physics on the fly); and a physical interface for computerised numerical milling machines (he has a patent on that last one).

His latest homespun invention, the Kaala printer, turns soot from pollution into black ink by combining it with alcohol and oils. It's at a very early stage, but Sharma hopes that the technology will help the environment in India's cities (and cut the cost of ink cartridges).

He also helps run the MIT Media Lab's India Initiative, which helps spread the inventor's spirit among students on the subcontinent. "We take them through the process of invention from ideation to creation," he says. "It's about saying: hey, what do you think we can change today?" **OF**

anirudh.me

Each pair of Lechal shoes can be paired with your mobile device for fitness, navigation and haptic purposes

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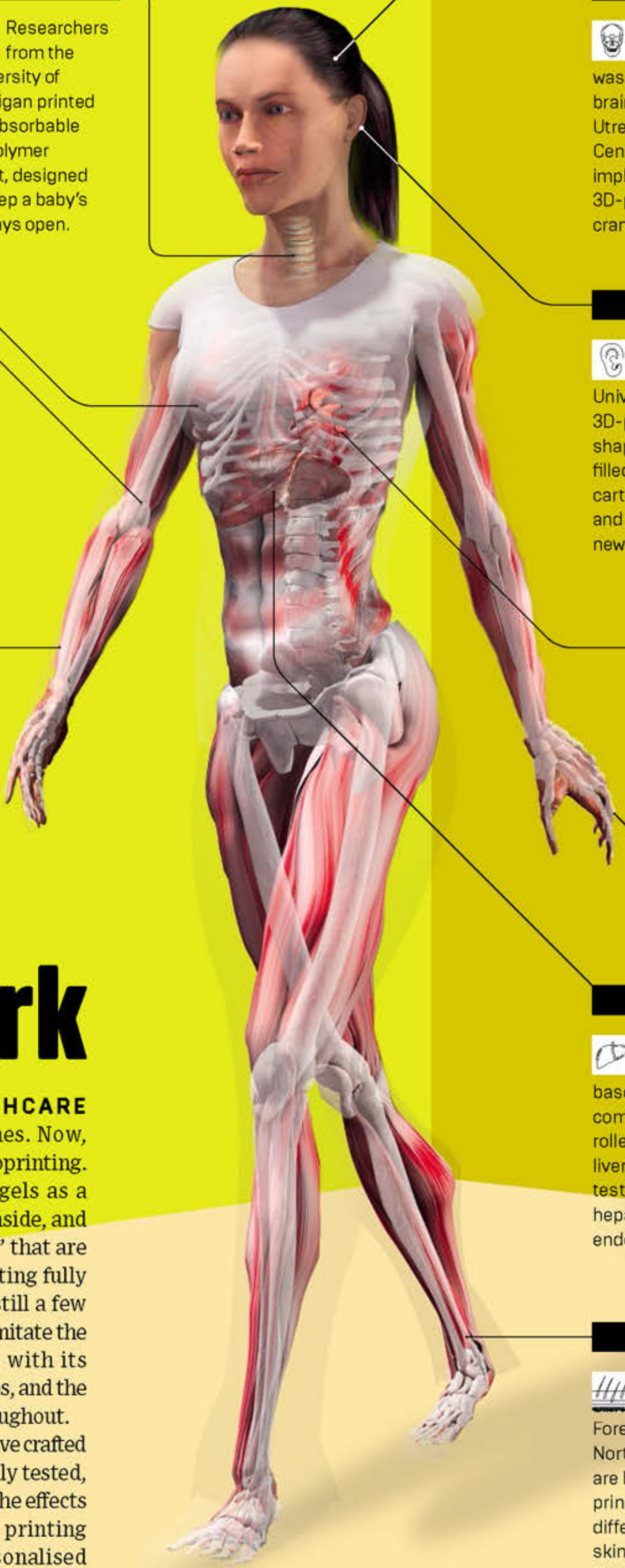
PURE

Body work

3D PRINTING IN HEALTHCARE used to mean replicating bones. Now, researchers are moving into bioprinting. This technique uses special gels as a medium for live cells to grow inside, and then turns these into "bioinks" that are placed inside a cartridge. Printing fully functioning human organs is still a few years off, as researchers try to imitate the complexity of human tissue, with its multiple cellular layers and types, and the networks of vessels spread throughout.

But the samples researchers have crafted so far are already being clinically tested, allowing scientists to measure the effects on humans more reliably. "3D printing moves us toward a more personalised medicine," says Jos Malda, a bioengineer at the Netherlands' Utrecht University. And what could be more personalised than blood vessels, heart valves and skin printed from your own cells? **Emma Bryce**



BREASTS

In 2014, researchers at the University of Texas at El Paso began 3D-printing cells to fill the void left by lumpectomies of cancer patients.

WINDPIPE

Researchers from the University of Michigan printed a reabsorbable biopolymer splint, designed to keep a baby's airways open.

SKULL

For a patient whose skull was pushing on her brain, surgeons at Utrecht Medical Centre successfully implanted a 3D-printed plastic cranium in 2014.

CAPILLARIES

Harvard University researchers have created something akin to living human tissue that could potentially provide printed organs with blood.

EAR

Bioengineers at Cornell University in the US 3D-printed an ear-shaped mould, then filled it with animal cartilage cells and collagen for a new ear to grow in.

SPLINT

Software designers at Loughborough University in the UK have programmed a 3D printer to turn scans of arthritis patients' arms into customised splints.

HEART

Doctors at the University of Louisville, Kentucky, are using a 3D printer that makes heart valves, veins and heart tissue out of human fat cells and collagen.

LIVER

Organovo, a San Diego-based bioprinting company, has rolled out printed liver tissue for testing. It includes hepatocytes and endothelial cells.

BONE

Doctors from Peking University Third Hospital printed a custom vertebra out of titanium powder and implanted it into a cancerous spine.

SKIN

Scientists at Wake Forest University, North Carolina are building a skin printer to print different types of skin cells for use on burn wounds.

ILLUSTRATION: DAN FOLEY

VIRTUAL UNREALITY

THE WORLD WITHIN A WORLD THAT CAN PROTECT YOU FROM HACKERS

EIGHT YEARS AGO, POLISH HACKER Joanna Rutkowska was experimenting with rootkits – tough-to-detect spyware that infects the deepest level of a computer's operating system – when she came up with a devious notion: what if, instead of putting spyware inside a victim's computer, you put the victim's computer inside the spyware?

At the time, a technology known as virtualisation was becoming easier to implement on PCs, allowing anyone to create a miniature OS, known as a virtual machine, inside their main OS. Rutkowska manipulated virtualisation into a mind-contorting weapon called a Blue Pill attack. Without them knowing, her rootkit moved the victim's entire OS into a virtual machine controlled by the hacker, allowing everything the target did to be watched. The victim's digital world would suddenly exist inside an alternate reality, and no amount of antivirus or antirootkit scanning could break the system out of that aquarium.

"Your operating system swallows the Blue Pill and it awakes inside the Matrix," Rutkowska wrote in a blog post explaining the trick. Eventually she honed the manoeuvre so that not even launching another virtual machine inside the Blue Pilled system would glitch the illusion – her attack supported a dream within a dream.

But as the years passed, no real-world instances of Blue Pill attacks were discovered, even after other researchers developed tests capable of detecting the technique. Rutkowska's explanation? For normal spies and cybercriminals, ordinary rootkits work just fine. "There are still so many places in a Windows kernel to hide traditional malware," she says. "I was as vulnerable as any other user. This was annoying."

So Rutkowska flipped the game. Four years ago her Warsaw-based firm, Invisible Things Lab, developed its own free, open-source OS known as Qubes. It lets users set up a collection of virtual machines on their PC, with a central interface to manage each quarantined system. Users can keep their online activities isolated in one virtual machine while they do their work in another and their banking in a third. (Rutkowska runs about 15.) Open a malicious attachment or click on an infected website and the malware can't break out of that one contaminated container.

Qubes currently works with Linux, though a Windows version is in beta testing. It requires serious geek chops to set up, but Rutkowska is working to make it easier to use and hopes to offer custom versions to corporate users. If it works as promised, even NSA-level exploits would be contained to a single compartment, one that could be evaporated and recreated at will. Recovering from even the nastiest hacker attack could soon be as easy as waking from a bad dream. **Andy Greenberg** *invisiblethingslab.com*

'There are still so many places to hide traditional malware in a Windows kernel. I was as vulnerable as any other user. This was annoying.'

ILLUSTRATION: DAVID DORAN

small cells
big power

15%* more powerful for innovative gadgets
GP custom-made energy solution

www.gpbatteries.com * based on size and volume

recharge with GP

Helping millions go with the flow

Designers are future-proofing London Bridge to ensure the only delays will be on the trains

OVER THE NEXT FOUR YEARS, LONDON BRIDGE STATION WILL UNDERGO THE biggest overhaul yet of a national terminus. It already handles 54 million passengers a year – a figure that is expected to rise 34 per cent by 2031 – and will be redesigned to accommodate this growth. To ensure the station's human traffic will flow freely, London-based designer and human factors consultancy CCD Design and Ergonomics, whose expertise has contributed to the design and layout of the Large Hadron Collider control room and Heathrow's Terminal 5, has been bought in to inform its design and functionality.

The consultancy's London Bridge work was informed by a "pedestrian flow modeller", which highlights where crowding and bottlenecks occur the most. "London Bridge is the first UK station to use such a modeller before it was redesigned," says Adam Parkes, principal human factors consultant at CCD. Once the flows were modelled, CCD visualised the routes that people would likely take through the station and mapped them on to the plan.

One CCD insight is to move the station's departure boards. Some will be beyond the ticket barriers to encourage travellers to move through the station when a platform is announced. "We know that the main pinch point is the flow of people getting off trains and those looking to depart," says Parkes. "Wayfinding routes have been designed to guide passengers on to the concourse, where there is more space."

CCD is now looking at the High Speed 2 rail project, where its research is informing how to easily move high volumes of passengers on and off a high-frequency service. If only it could also improve the rail service... **Clare Dowdy** *ccd.org.uk*

FIND THE GAPS

Four CCD factors that will help prevent London Bridge Station from overcrowding:

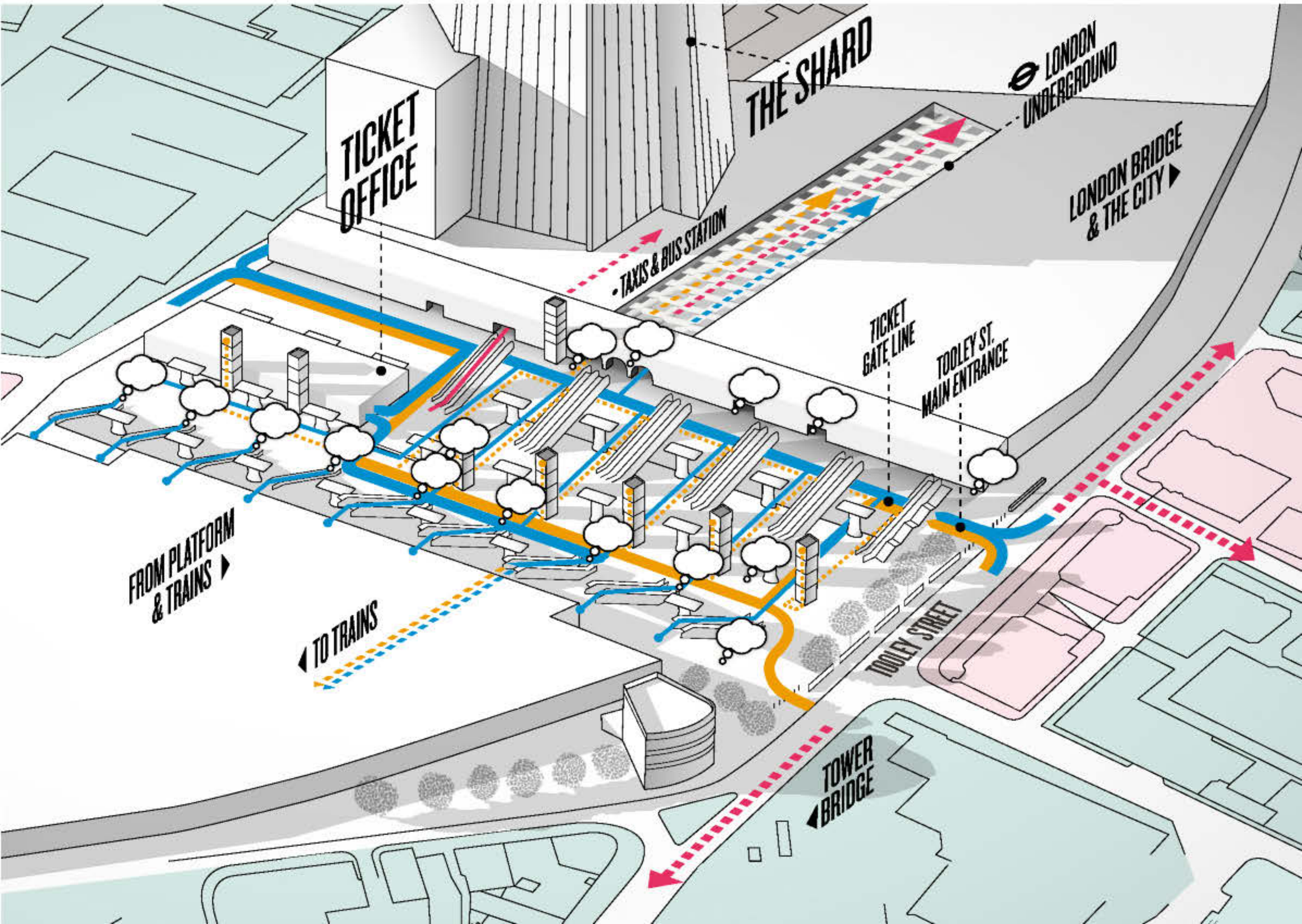
🟧 Station route for ticket holders only

🟦 Wayfinding route from train to tube

🟥 Reduced-mobility route via lifts

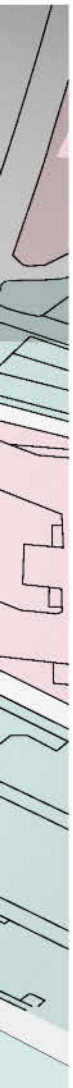
☁ Decision point with directional signage

PHOTOGRAPHY: JAMES DAY; ILLUSTRATION: BILLY CLARK; GIACOMO GAMBINERI



COOL IF YOU'RE 14

Smart Pants – silicone underwear for your smartphone – are now on the growing list of weird things teens buy from vending machines in Japan. They offer no protective function whatsoever, beyond making your phone look so naff a thief might think twice about stealing it. *bandai-asia.com*



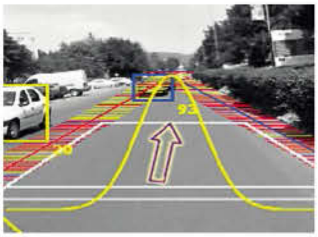
SELF-DRIVEN CARMAKER FROM HACKERVILLE

In 2011, Ionut Budisteanu read about Google's self-driving car project and decided to build one himself. So the 18-year-old, from Râmnicu Vâlcea (also known as Hackerville) in Romania, started writing algorithms that could recognise images of traffic signs, lanes and other objects from the camera feeds.

His biggest obstacle: the cost of 3D LiDAR, the remote-sensing technology that measures distance. "I realised that [Google's] LiDAR system costs about $75,000 [£47,000]," says Budisteanu, now 21. "So I decided to make my own. My LiDAR only had 18,000 pixels but it cost about $200." His system, which he built around his father's Fiat, can recognise buildings from 100m, and humans from 20m.

Budisteanu, a WIRED Innovation Fellow, started programming when he was 11. After playing computer games for years, he started making his own. He designed his first antivirus software in year six and his own programming language in secondary school. Inspired by his blind uncle, he also designed a device that enables a visually impaired person to identify objects with their tongue. "I undertake these projects to learn and to challenge myself," he says.

Budisteanu is now focused on a new project: a pick-and-place robotic machine, called VisionBot. "I want to create an infrastructure to help makers and engineers turn their prototypes into industrial products," he says. **JM** *budisteanu.net*



Budisteanu's car uses GPS and three cameras to gauge on-road obstacles

Surface.co.uk

Microsoft

The tablet that can replace your laptop.

The new Surface Pro 3 is a tablet and laptop in one. It’s thin and light and runs your favourite desktop programs, like Adobe Photoshop, Office and Windows. Work from anywhere with built-in adjustable Kickstand, Surface Pen, USB port, 12-inch screen, and an optional click-in keyboard. The Surface Pro 3. The tablet that can replace your laptop.

Surface Pro 3

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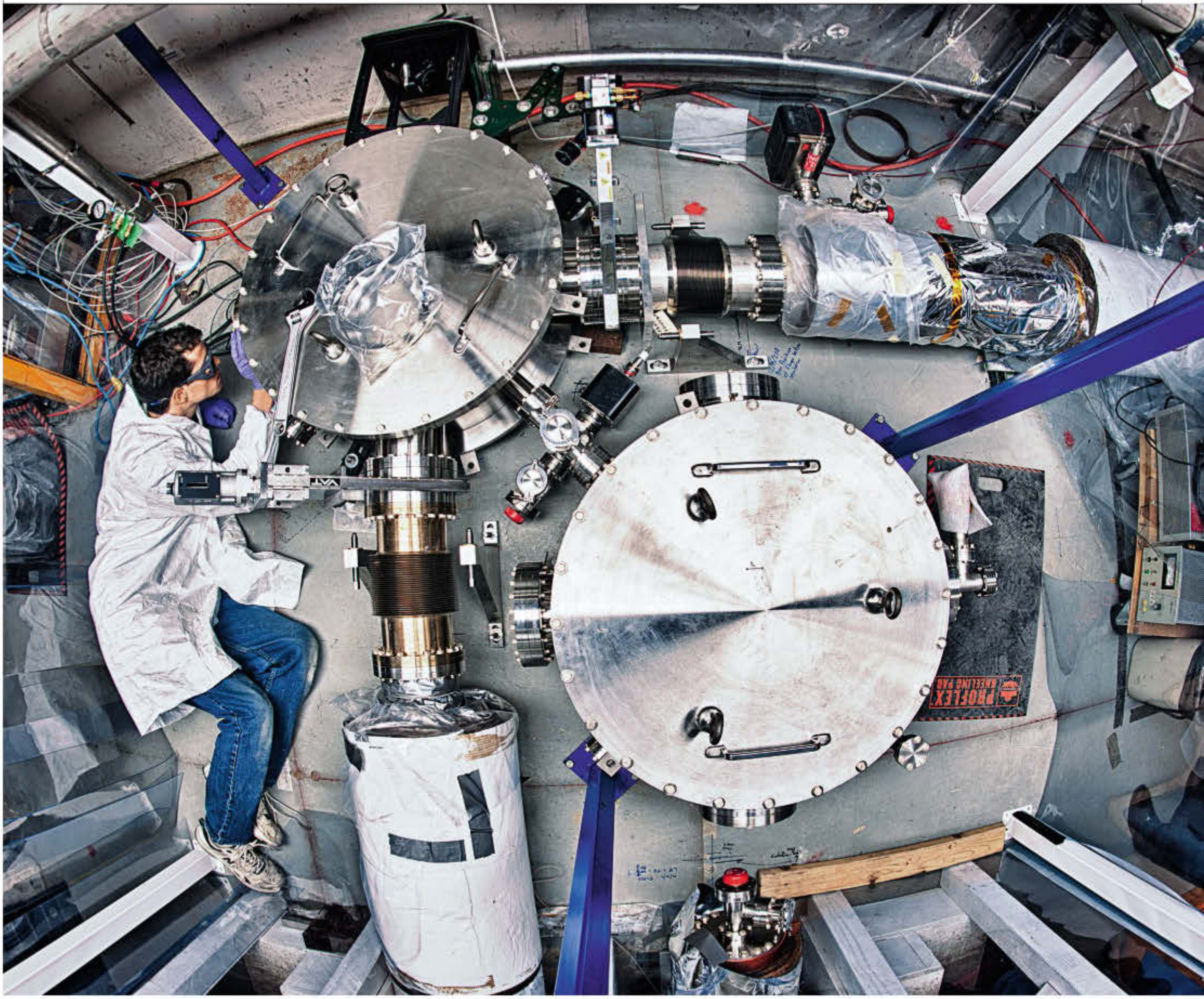


Dimension data

Fermilab is finding out if the Universe is flat. Don't panic, the world will remain spherical

SCIENTISTS AT CHICAGO'S FERMILAB BELIEVE OUR UNIVERSE COULD BE A hologram – and they've built what they claim is "the world's most precise instrument" in an attempt to prove it. The instrument, known as the Holometer, uses lasers to detect the movement of particles by the tiniest of margins: a billionth of a billionth of a metre, almost a billion times smaller than an atom. The particle's position will help test the scientists' theory.

"The idea derives from the discovery that when anything is sucked into a black hole all the information for that 3D object is encoded across the black hole's two-dimensional surface," explains Aaron Chou, lead scientist and designer of the Holometer experiment. "Unlike a photo, which loses much of the 3D information, a black hole manages to encode all of it in 2D form." The holographic model proposes that this is the case everywhere – that our apparently 3D Universe is fundamentally flat. If the theory is correct, Chou explains, then it also predicts that the Universe is made up of "tiny two-dimensional bits, like the pixels of a digital image". An understanding of how a full 3D universe could be encoded in tiny two-dimensional pixels could have far-reaching consequences far beyond the speculations of theoretical physicists. "Certain computations of three-dimensional objects can be more easily calculated with two-dimensional encoding," says Chou. "If our research bears fruit, we might come up with new paradigms for computing, for more efficient encoding of information and more powerful algorithms." **KN** *fnal.gov*

The Holometer is housed in a tunnel at Fermilab's base in Batavia, Illinois

WHAT'S EXCITING...

YUELIN LI

Co-founder of investment platform Alice

"I'm looking forward to the launch of the **Activité** smart watch by the French smart-health company Withings. It'll be my first foray into the Quantified-Self world. It has a beautiful big dial, simple calfskin strap (supplied by the venerable Tanneries Haas) and lots of really great features. It's contemporary, yet an instant classic."

WHAT'S EXCITING...

STEPHEN RAPOPORT

Founder and CEO, Pact Coffee

"I find **Wool and the Gang** incredibly inspiring. Their community-designed and -produced knitwear is a reminder that, far from being a new concept, peer-to-peer economies are a wonderful human idea that was half-killed by consumerism, but has been given new life by the social nature of the internet."

WHAT'S EXCITING...

JEH KAZIMI

Founder and CEO, Breezie

"Gesture-based and voice-activated controls to augment touch-enabled devices – for example, the **Myo Armband**. As our reliance on touch-based interfaces grows, it limits any interaction with smart devices if they are out of our reach. Consumerisation of this technology improves accessibility for our future users."

WE WON'T BE BUYING

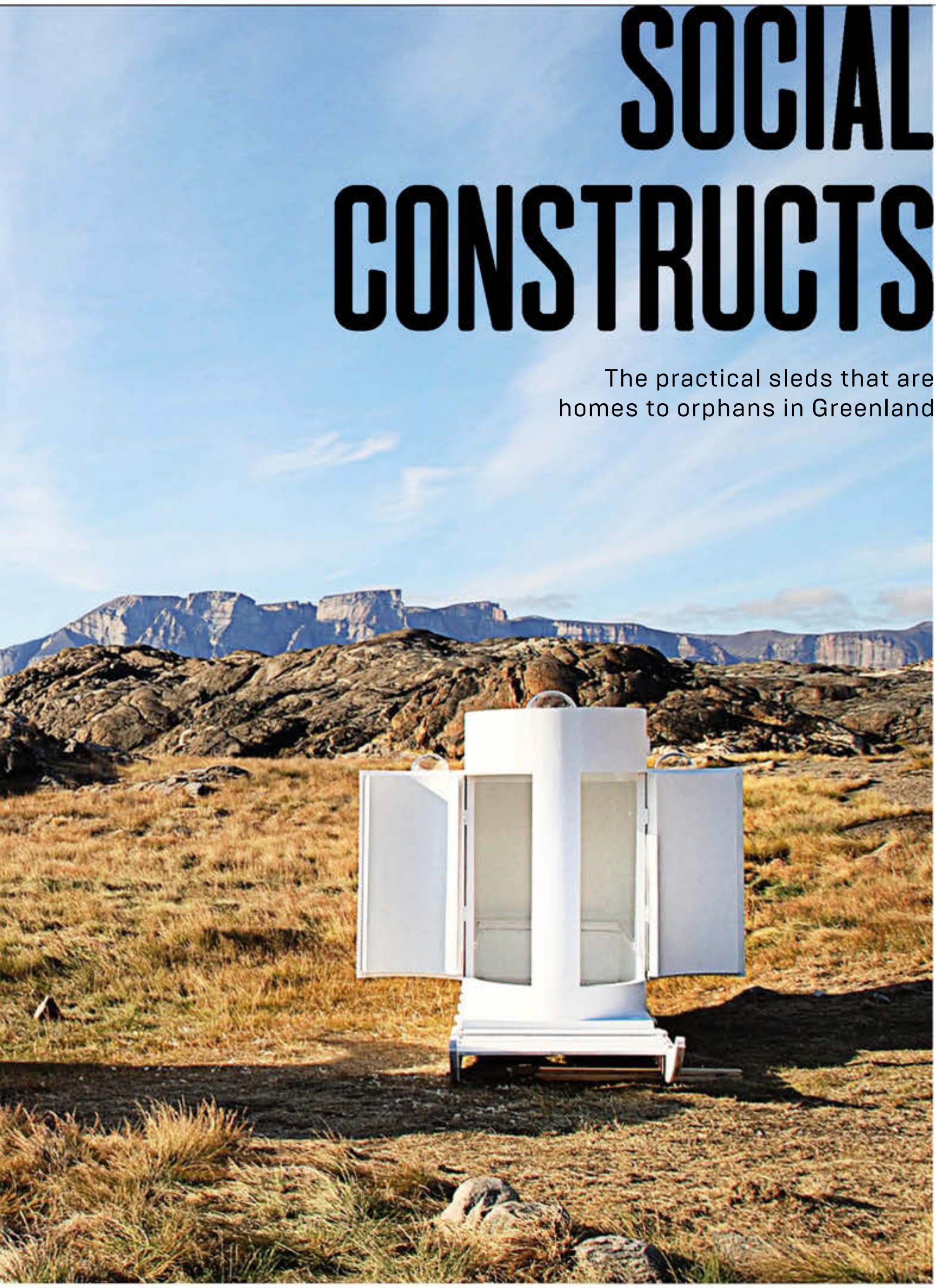
Alibaba – the gigantic Chinese e-commerce site – may have had the world's biggest IPO, but that doesn't mean we are buying into all its wares. Five things to avoid: a life-size model of Steve Jobs; a bath float for your laptop; an animatronic dinosaur; a full-size roller coaster and 100 ninja throwing-star-shaped USB drives.

GOOD VIBES FOR THE DEAF

Music is a force so potent, even those who cannot hear can appreciate it. Sound, after all, can be thought of as "touch at a distance," as perceptual neuroscientist Diana Deutsch of the University of California in San Diego puts it. By feeling the vibration of air molecules, deaf people can experience music – particularly bass-heavy genres. "People who come to my nights in Bristol are always surprised – 'the promoter is deaf?'" says events producer Jacob Casselden, who is fully deaf. This October, he spearheaded Sencity in London, a rave that brings the deaf and the hearing together through a mutual appreciation of music. To cater for this, a slew of new music-listening devices for the deaf are on offer. **Zoe Cormier**

SOCIAL CONSTRUCTS

The practical sleds that are homes to orphans in Greenland



HIGH ABOVE THE ARCTIC CIRCLE, on the tiny island of Uummannaq in Greenland, Dutch designer and architect Rob Sweere has built two mobile Inuit homes – on top of ice-sleds. The insulated homes, each of which can house six people, were built as shelters for orphaned Inuit children. “The children’s home in Uummannaq takes in disabled, orphaned and other Inuit children and teaches them a traditional Greenlandic way of life – they learn to fish and hunt with Inuit hunters,” says Sweere. The problem: it was dilapidated and overcrowded, so they asked Sweere to help build hardy shelters to brave Arctic winters.

First, building materials (mainly wood and acrylic) were flown in from Denmark, and brought out to Uummannaq on open boats. Next, Sweere designed the homes attached to sledges, which could be dragged on sea-ice by snow scooters or dogs. “Everything in Greenland is done on sledges during winter – they literally live on the ice,” says Sweere. Each structure is made from medium-density fibreboard wood, with two rounded porthole-like acrylic windows. “Acrylic can withstand extreme frost and the double insulated walls keep the inside very warm,” he says. Each home is fitted with wooden benches and a tabletop, which double as beds. “[Inuits] are used to living and sleeping in a space in groups of six to eight people, so your body heat heats the room,” Sweere says. His next project: an Inuit home that floats on the sea, among the icebergs. **MV** *robsweere.com*

VIBROY

For just $10 (£6), this small, sticky device can “turn anything into aspeaker”: furniture, cardboard boxes – even your finger. “I also find itworks quite well placed on my collarbone or located just behind my ear,” says Casselden. *thinkgeek.com/product/eaf8/*

EMOTI-CHAIR

Inspired by the structure of the inner ear, this converts musical notes into tactile vibrations – high pitches at the top of the chair, bass notes at the feet. Several hundred have been made, custom-built for each patron. *ryerson.ca/psychology/emotichair.html*

SENSE FLOOR

Composed of 32 vibrating square panels, Sencity’s “Sense Floor” has travelled the world over. Vibrating engines transduce musical notes into shuddering pulsations. Though designed for the deaf, it can enhance acoustic sensations for anyone. *your-sencity.com*

HEADBONES

Inventor James Talbot wanted to create headphones that hearing people can use while running or cycling. The result: Headbones, which transmit music to the inner ear via gentle vibrations on the temporal bone of the skull. *damsonaudio.com/headbones*

ILLUSTRATION: GIACOMO GAMBINERI

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Condiment power

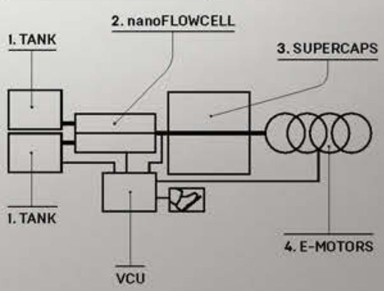
Salt is the secret ingredient in this zero-emission car

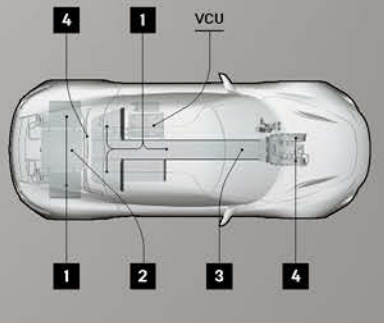
BUILT BY LIECHTENSTEIN-BASED RESEARCH FIRM nanoFLOWCELL, this is the Quant e-Sportlimousine. The electric car contains a new battery technology that, the company claims, can provide five times more energy than lithium-ion batteries – the standard used in electric vehicles. The car is being road tested in Germany, Switzerland and France and the company says the higher energy density can power the vehicle to 350kph, and to 100kph in just under three seconds. "We currently demonstrate a technological edge of about 15 to 20 years," says Nunzio La Vecchia, the company's chief technology officer.

Flow-cell batteries, on which the Quant runs, generate energy by pumping two electrolyte solutions – in this case saline solutions, one negatively charged, the other positively – over complementary electrodes in two halves of a battery pack. That creates a voltage difference, which drives ions across a central membrane between the two halves, and electrons through an external circuit. This creates a current that flows through two supercapacitors (supercaps) to the e-motors, controlled by the vehicle control unit (VCU). The Quant contains two 200-litre tanks of this solution surrounding the nanoFLOWCELL battery. Flow cells can cut emissions completely and are long-term sources of energy – but they also tend to be costly and less powerful than other fuels. "Finding materials that are inexpensive, have very fast reaction rates and a high energy density is challenging," says Anthony Kucernak, a professor of chemical physics at Imperial College London. "If [nanoFLOWCELL] has achieved this, it would certainly be exciting."

The company expects vehicle approval by 2016 and is working on two more prototypes of the car. "The nanoFLOWCELL has the potential to bring about a revolution of electric mobility," says La Vecchia. Next is exploring its potential to power railways, ships and planes. **Emma Bryce** *nanoflowcell.com/en*

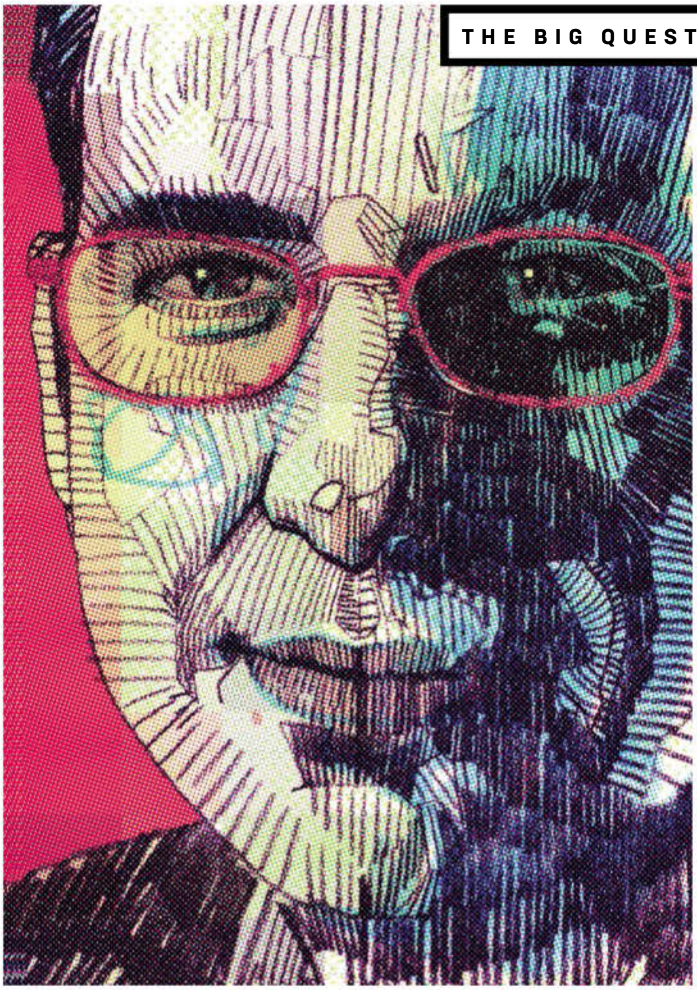
SALT SOLUTION





How will we fight cybercrime over the next ten years?

THE BIG QUESTION



KEVIN MITNICK

FORMER FBI MOST-WANTED HACKER; TEAM LEADER, THE GLOBAL GHOST TEAM

“What has been clearly demonstrated over the last decade is technology is not keeping pace with hackers, and manipulation using social engineering is now the preferred method of crime. People are the weakest link and we must build the human firewall. Everyone must role-play – a proven technique used in other areas of business. Through the war-gaming strategy of ‘red teaming’, your organisation must engage third parties to mimic the real bad guys that are trying to penetrate your systems, your people. Only when challenged will you know if your security is effective. Installing something no longer means security.” **Kathryn Nave**

JAMIE SAUNDERS
DIRECTOR, NATIONAL CYBER CRIME UNIT AT THE UK NATIONAL CRIME AGENCY

“The fight against cybercrime will benefit from greater attention to cyberhygiene from individuals and businesses, but more of the fight will be taken ‘upstream’ to the sources of global cybercriminality. Digital capabilities will be more ingrained into all UK law-enforcement bodies, and there will be a larger international community of investigators with the skills to do the job.”

SÉBASTIEN MARCEL
HEAD OF BIOMETRICS, IDIAP RESEARCH INSTITUTE, SWITZERLAND

“Biometrics are becoming more prevalent for devices to recognise nomadic users, but there are legitimate concerns. It might be possible to forge a fake biometric [input] from a leaked template and to perform a presentation attack – AKA spoofing. We’ll see a lot more research on privacy-preserving mechanisms for presentation-attack detection – AKA anti-spoofing.”

GADI AVIRAN
FOUNDER AND CEO, SENSECY

“Cybercrime has gone global – the thief stealing from my computer probably does not live in my country, let alone my continent. In ten years’ time, we will understand cybercriminals far better – both their MOs and their psyche. Law-enforcement agencies will have to co-operate globally, and vendors and governments must come together and create higher standards for products and services.”

ANGELA SASSE
DIRECTOR, THE RESEARCH INSTITUTE IN SCIENCE OF CYBER SECURITY

“In ten years, we will have security that is largely invisible to legitimate users, and that delivers added value. Today, security gets in the way of people’s activities, and requires too much time and attention. People are tired of mental gymnastics and being interrupted by warnings when they go online. Future services will deliver security and privacy as part of a great customer experience.”

COLONEL ARTUR SUZIK
DIRECTOR, NATO COOPERATIVE CYBER DEFENCE CENTRE OF EXCELLENCE

“Success in fighting cybercrime will, in the long run, critically depend on international law-enforcement co-operation. Criminals act across borders and will happily continue exploiting the jurisdictional constraints of national law enforcement. Governments and international bodies will need to continue developing effective cross-jurisdictional collaboration mechanisms.”

ILLUSTRATION: DWAYNE BELL

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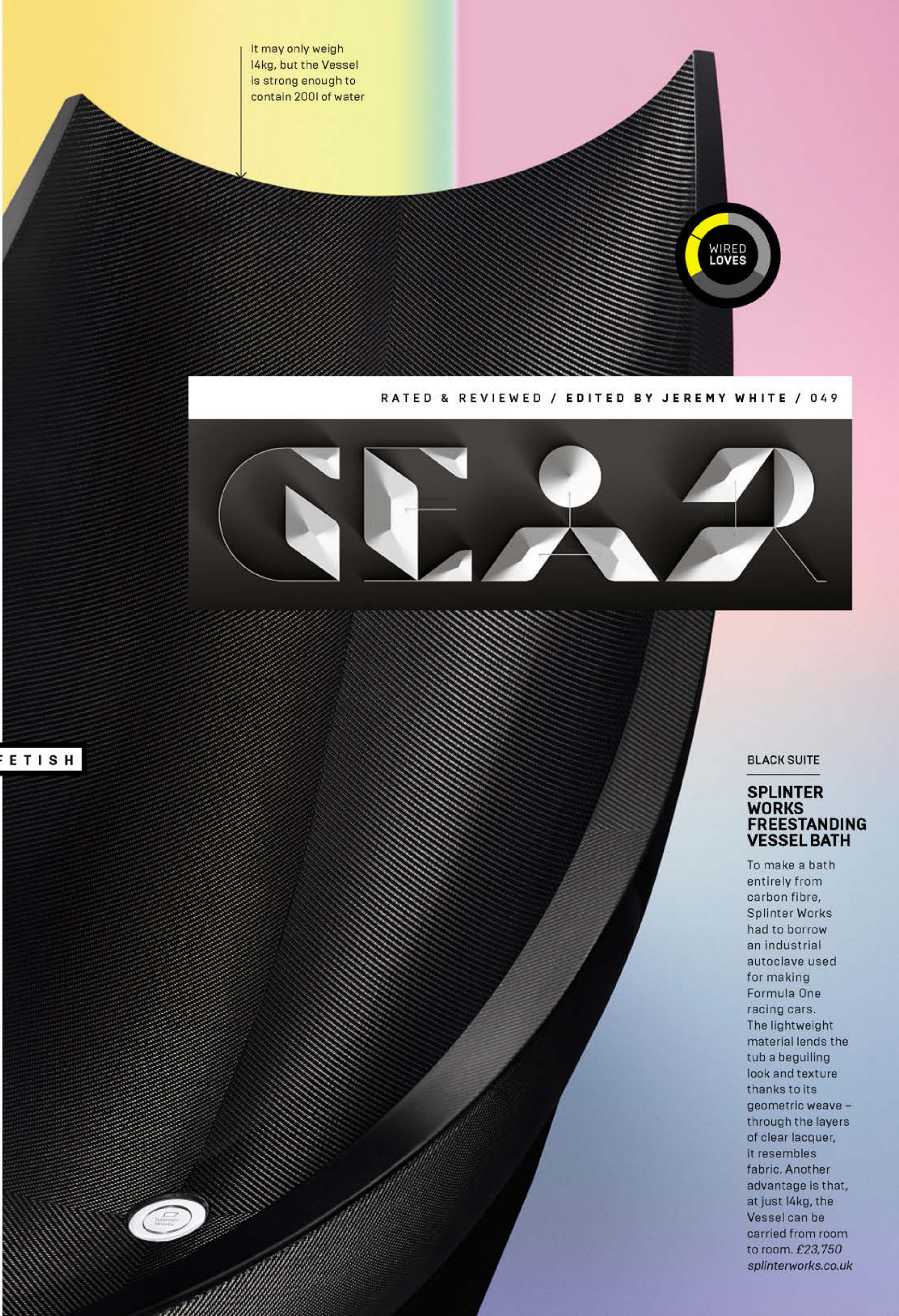
GEAR


It may only weigh 14kg, but the Vessel is strong enough to contain 200l of water

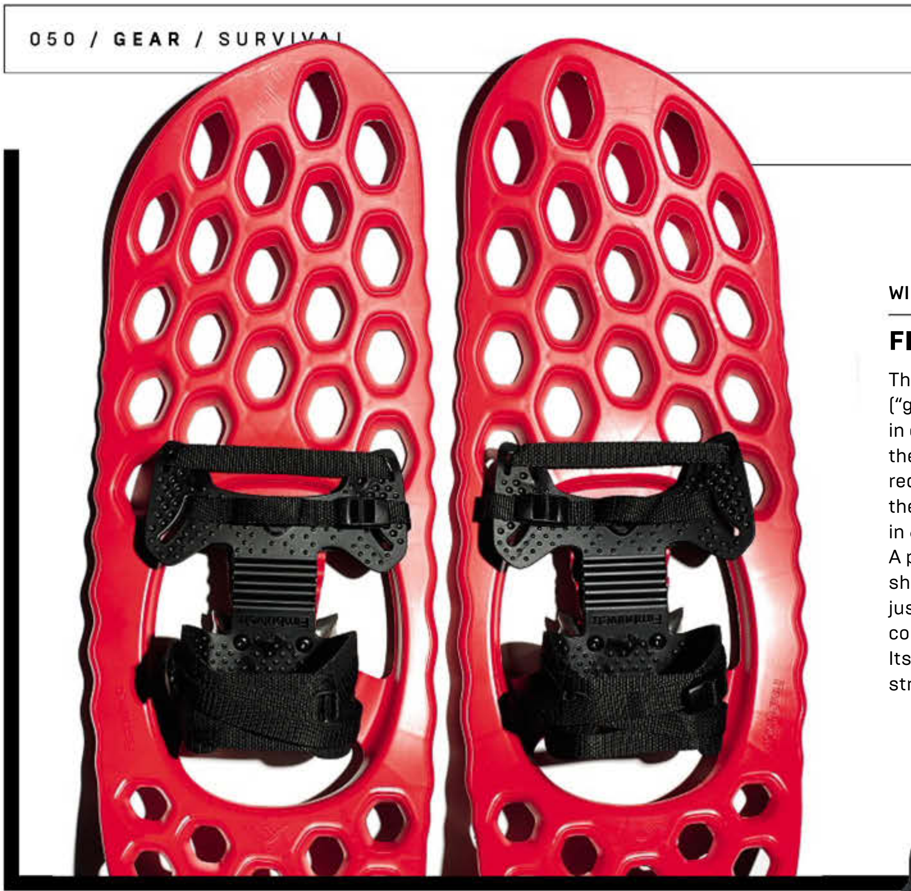
FETISH

BLACK SUITE

SPLINTER WORKS FREESTANDING VESSEL BATH

To make a bath entirely from carbon fibre, Splinter Works had to borrow an industrial autoclave used for making Formula One racing cars. The lightweight material lends the tub a beguiling look and texture thanks to its geometric weave – through the layers of clear lacquer, it resembles fabric. Another advantage is that, at just 14kg, the Vessel can be carried from room to room. *£23,750 splinterworks.co.uk*

WORDS: JIM HILL. PHOTOGRAPHY: GARY SMITH



Don't like Rescue Red? Try Just Black or Snow White

WINTER WALKERS

FIMBULVETR SNOWSHOES

The Fimbulvetr ("great winter" in old Norse) is the most radical redesign of the snowshoe in 6,000 years. A plastic unibody shoe, it uses just 12 recyclable components. Its honeycomb structure lends the thermoplastic elastomer both strength and traction, while minimising materials. An asymmetric ripple in the shoe allows the wearer a more natural stance and reduces the chance of tripping. *€310 fimbulvetr.no*

FETISH

RUGGED REMOTE

CASIO G-SHOCK GBA-400

Casio's chunky multifunction watch gains yet more abilities thanks to the *G'MIX* and *G-SHOCK+* apps. When paired (via Bluetooth) with an iOS or Android phone, both apps let you control music playback using your watch; *G'MIX* also adds SoundHound track identification and an equaliser, and *G-SHOCK+* lets you control watch functions from your handset. *£161 g-shock.co.uk*

HIGH-POWERED RADIO

SOULRA FRX3

This portable radio has four energy sources – so if the 2,000mAh lithium battery runs flat, the Sun won't shine on the solar panel and you have no AAA batteries, there is always the hand crank. Four minutes of winding gives ten minutes of airtime. There's also a flashlight and a charging port for your phone. *£59.99 soulracorp.com*

HARD CASE

SOL ORIGIN SURVIVAL KIT

Everything in this palm-sized waterproof ABS plastic case is an essential survival tool – even the lid doubles as a signal mirror. Inside, and housed in slots, are a compass, fire starter, cord, steel wire and a lock-blade knife with a whistle and LED torch built into the handle. The contents were compiled by survival specialist Buck Tilton – you'll find 62 of his essential tips in his booklet, also in the kit. *$40 surviveoutdoorslonger.com*

WORDS: JIM HILL, JEREMY WHITE. PHOTOGRAPHY: SUN LEE; DAVE LIDWELL. HOTNESS: MIKE DENT

RAY ZAHAB'S SURVIVAL TIPS

The Canadian ultra-marathoner shares his tactics

1. Block
Wind chill can lower temperatures by 20°C, so cover up.

2. Layer up
Layers are warmer than a single thick item of clothing.

3. Hydrate
Even in extremely cold conditions, you'll need to drink plenty of liquids.

Survival of the techest

Gear to increase your odds of making it through the wilderness

COSY COAT

CANADA GOOSE SNOW MANTRA

Developed for the coldest regions on the planet, the Snow Mantra keeps you cosy in temperatures down to -30°C. Features include a three-way-adjustable tunnel hood with a windproof bracing wire, and two mesh kidney-pouches with Grabber biodegradable warmers to keep your vital organs from freezing. The jacket owes its incredible warmth to the use of 675-fill-rated white goose down and feather. *£1,200*
canada-goose.com

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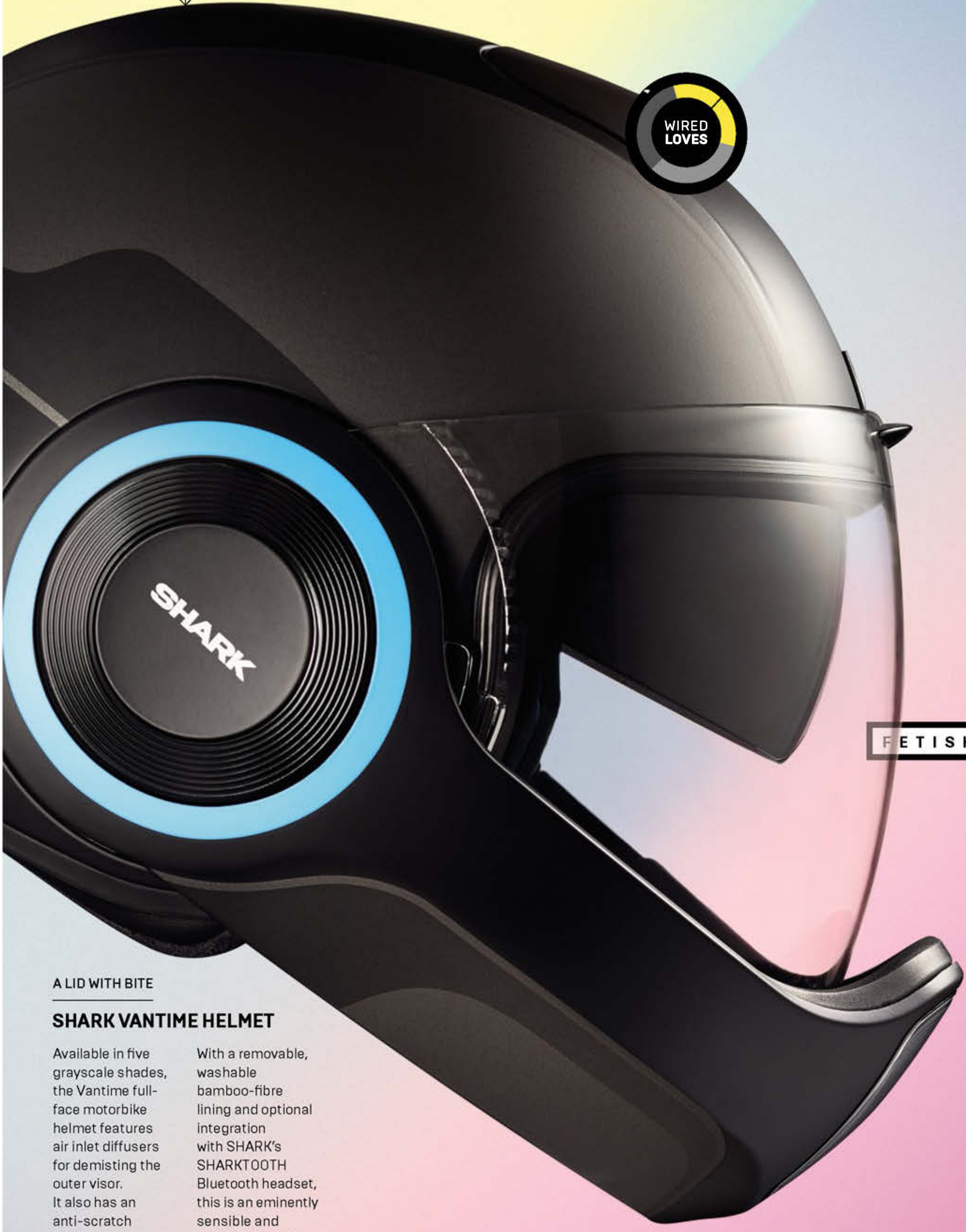


The Vantime is made from injected thermoplastic resin and comes in five sizes

WIRED LOVES

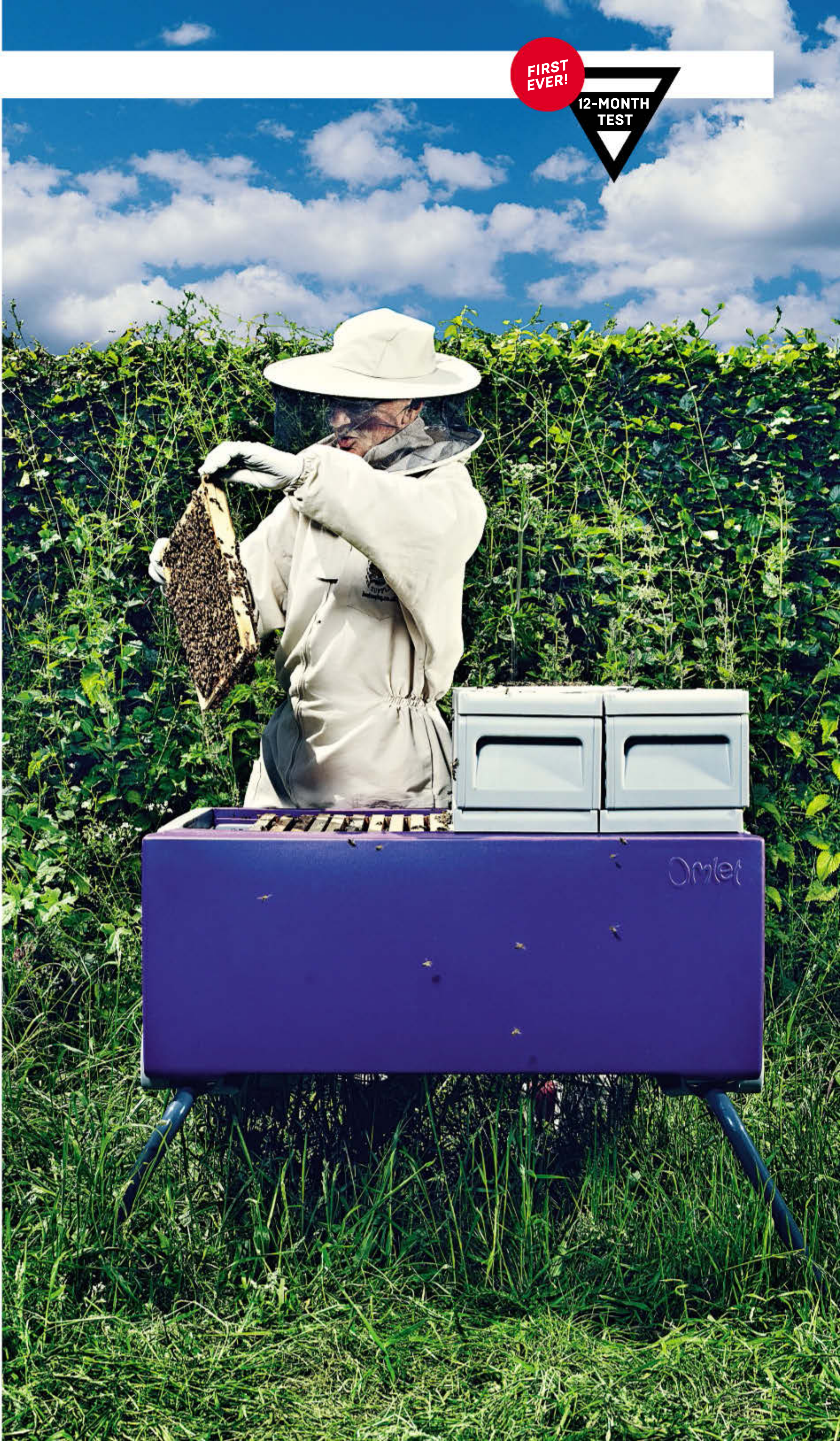
FETISH

A LID WITH BITE

SHARK VANTIME HELMET

Available in five grayscale shades, the Vantime full-face motorbike helmet features air inlet diffusers for demisting the outer visor. It also has an anti-scratch UV flip-down internal Sun visor to restrict glare. With a removable, washable bamboo-fibre lining and optional integration with SHARK's SHARKTOOTH Bluetooth headset, this is an eminently sensible and stylish lid for urban riders. *From £170 shark-helmets.com*

WORDS: JIM HILL. PHOTOGRAPHY: GARY SMITH



Jack Chapman has been beekeeping for ten years and has several hives across Surrey

The Beehaus

The plastic Beehaus is available in white, green, red, yellow or purple and comes fully assembled. It arrives with a handy divider, so you can raise two colonies side by side, or one larger one. "I like this flexibility," says Chapman. "It's worth considering for the urban beekeeper with limited garden space." No spring honey was produced in our test, probably due to bees fighting under the mesh floor in February. Flame-sterilising a plastic hive isn't possible – you have to use hot washing soda here, which was messy and inconvenient. And the lack of an easily removable floor makes it difficult to clean. **7/10** *£499 omlet.co.uk*

Size of colony Six frames (or three on each side)
Honey collected 13.6kg
No of cells for eggs or honey 150,000
Winter temperature 18.3°C to 21.1°C

Buzz feeders

What does it take to become hive-minded? We test three beekeeping kits to find out

Cedar National Hive

This beautifully crafted wooden hive mimics the natural habitat of wild beehive colonies that live in tree cavities. "We chose this design as it's the standard by which other hives should be measured against," says Chapman. "There are a lot of cheap hives in circulation that are made of soft wood, but this is made of cedar, which is durable and relatively lightweight." He pointed out that about 90 per cent of the beekeeping equipment is designed for wooden beehives, so interchangability will be convenient and easy. No fiddly strap is required to secure the roof on the hive – but a house brick placed on its flat roof works fine if you want to be sure. **8/10** *£153 caddon-hives.co.uk*

Size of colony Three frames **Honey collected** 38.5kg **No of cells for eggs or honey** 75,000 **Winter temperature** 21.1°C to 23.9°C

HOW WE TESTED

With the help of beekeeper Jack Chapman, WIRED tested three hives in the National Trust's Polesden Lacey orchard over a 12-month period. Each was assessed on design, hive material, functionality for the beekeeper and the amount of honey produced. A 2013 queen and five frames of brood were used in each. Using a Lascar Electronics data logger, Chapman measured the temperature and humidity of each hive throughout the winter to test their thermal properties.

JACK CHAPMAN'S BEEKEEPING BUZZWORDS

Husbandry
The process of managing a colony through the seasons.

Super
A box used to collect honey.

Thermal properties
The better the insulation, the larger the colony at the end of winter.

Brood
Bees that are at the egg, larva and pupa stage.

National Hive
The British Standard hive is the most commonly used in the UK.

National High Density Polystyrene (HDP) Hive

The team behind this polystyrene hive claims it has superior insulation and waterproofing to a wooden model. Indeed, its internal temperature throughout winter was consistently 3°C to 5°C higher than the other hives on test, resulting in a larger colony by March and more spring and summer honey than its rivals. The hive components are interchangeable with the National Hive design, but it needs to be painted every two years (this does mean you can choose your own colour, though). It's lighter than a wooden hive, so a strap is supplied to stop the roof blowing off in high wind. **9/10** *£102 beehive supplies.co.uk*

Size of colony
Four frames
Honey collected
45.3kg
No of cells for eggs or honey 75,000
Winter temperature
23.9°C to 26.7°C

You'll need to sterilise the HDP hive with a hot soda solution

WORDS: EMILY PECK. PHOTOGRAPHY: SUN LEE

EARLY RIDER

4MOMS ORIGAMI STROLLER

If there's a more WIRED stroller, we've yet to see it. The 12kg Origami opens and closes itself at the touch of button, drawing power from batteries that are charged as you push along. This also allows for built-in headlights and LED pathway lights that turn on automatically in dark conditions. On the handlebar, an LCD dashboard displays data such as distance covered – and you can, of course, charge your mobile via USB. Add in four-wheel suspension and a pair of cup holders, and your bundle of joy will be the envy of the kindergarten. *£930 4moms.com*

The generators top up the battery, but for a power boost you can plug it in every few weeks

WIRED LOVES

FETISH

Tablet extra!
Download the WIRED app to read extended reviews of the tablets

Microsoft Surface Pro 3

With its Windows 8 Surface Pro 3, Microsoft proves that if you want something doing right, you have to do it yourself. The 12-inch, higher-than-HD, 2,160 x 1,440-pixel screen is pin-sharp, and a 1.9GHz Intel Core i5 CPU and 4GB of RAM ensured *Half-Life 2: Episode Two* played very comfortably at near-maximum graphics settings. Although it has the performance to replace your laptop, you'll need the £110 keyboard/cover – pricey, but a worthwhile investment. **7/10** *from £639 microsoftstore.com*

CPU 1.9GHz **RAM** 4GB **Display** 2,160 x 1,440p **Weight (tablet)** 800g **Battery life (browsing)** 9hrs

Tablets take on laptops

These touchscreen powerhouses aim to replace the main computer in your life

HOW WE TESTED

WIRED compared form factors for style, ease of use and suitability to being both a tablet and a laptop. We used Valve's older game *Half-Life 2: Episode 2* to gauge 3D graphics performance. As benchmarking the different operating systems on offer wouldn't really compare like with like, we based ratings on real-world usage: browsing popular websites and navigating between pre-installed applications.

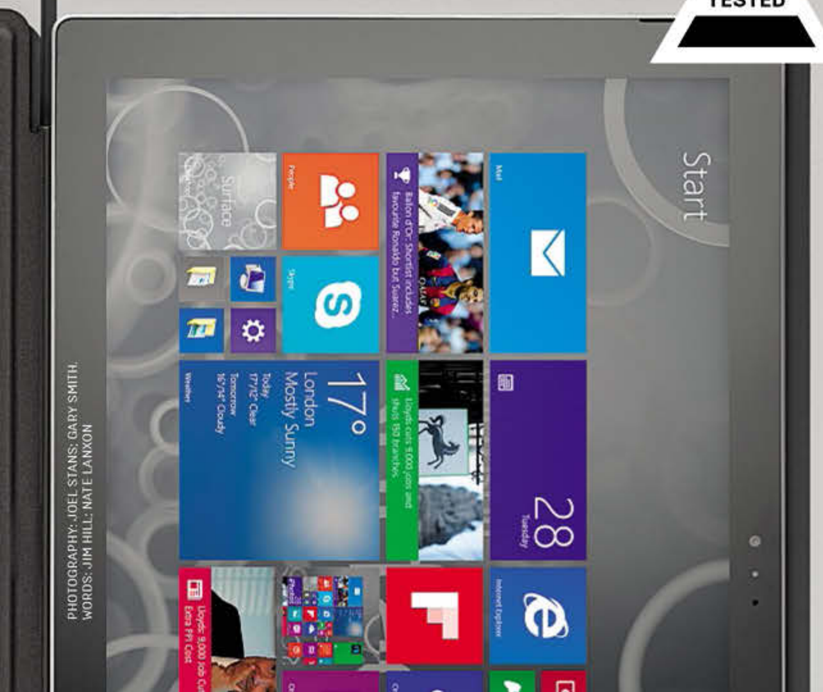
▲

Samsung Galaxy Note Pro 12

The Note Pro 12 is a 12-inch tablet aimed at demanding users. Unlike the rest of this Test group, it runs Android and, as such, adopts a tablet first, PC second approach to productivity. Performance from the 1.9GHz CPU and 3GB of RAM was nippy underneath the 2,560 x 1,600-pixel screen, but despite its impressive spec, it's not a true laptop replacement – the lack of custom corporate software compatibility alone may preclude it from any truly "pro" usage. **7/10** *from £400 samsung.com*

CPU 1.9GHz **RAM** 3GB **Display** 2,560 x 1,600p
Weight (tablet) 734g **Battery life (browsing)** 13hrs

TESTED



▲

Lenovo Miix 2

Lenovo's 11.6-inch Miix 2 has a 1.6GHz i5 CPU and 4GB of RAM, but it's a bit sluggish – *Half-Life 2: Episode Two* at full HD is unplayable. But it's fine for everyday use – and it comes with a keyboard. **6/10** *£599 shop.lenovo.com*

CPU 1.6GHz
RAM 4GB **Display**
1,920 x 1,080p
Weight (tablet)
800g **Battery life**
(browsing) 6hrs

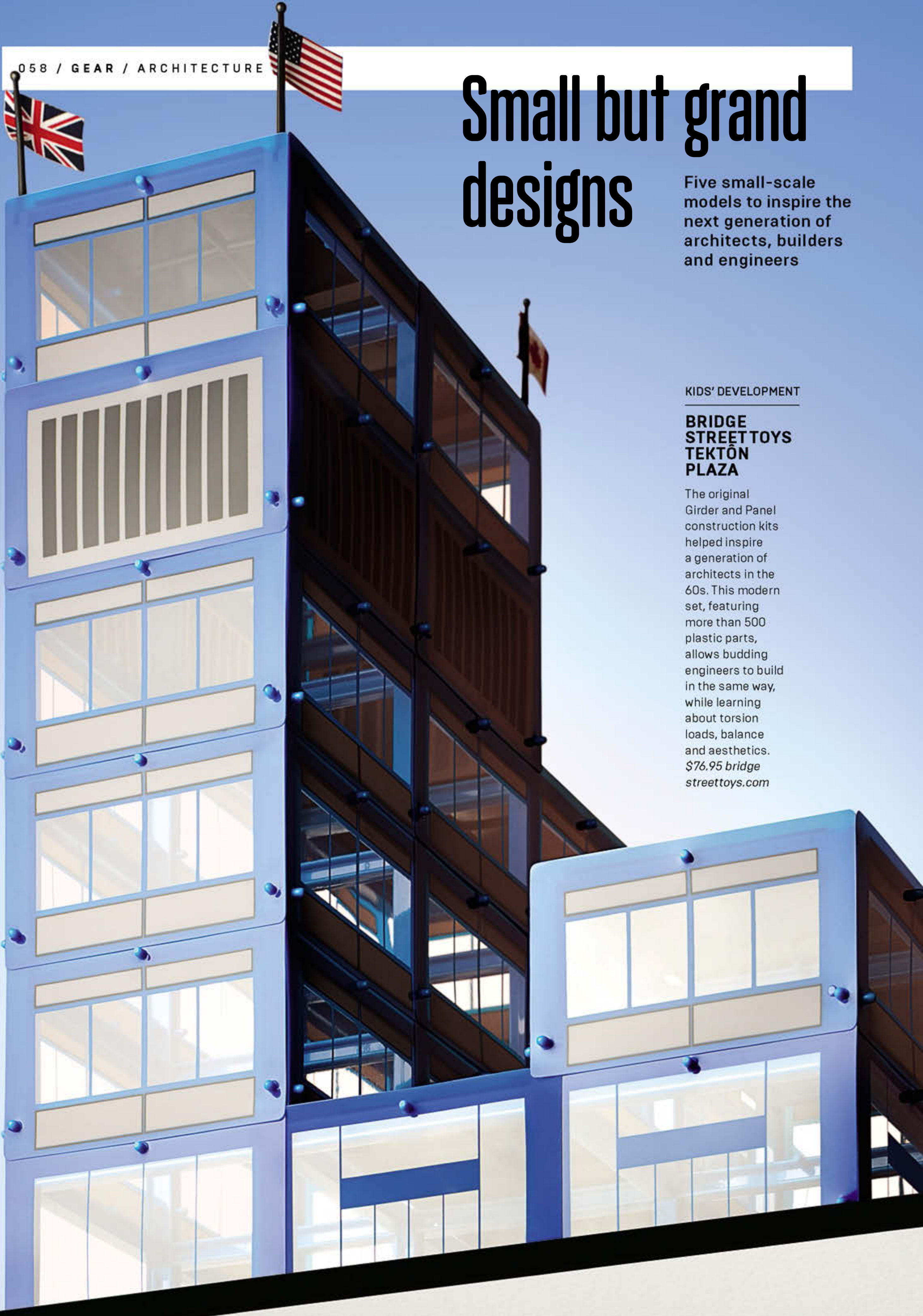
APPLE MACBOOK AIR 13-INCH

Microsoft thinks its Surface Pro 3 is a MacBook Air killer. The Pro 3 easily beats the Air in terms of chip speed (1.4GHz vs 1.9GHz) and resolution (1,440 x 900p vs 2,160 x 1,440p), but the Air is still extremely capable – plus it can run Windows 8 if you prefer. And unlike the Pro 3, it has no tablet/laptop identity crisis. *From £849 apple.com*

PHOTOGRAPHY: JOEL STANS; GARY SMITH
WORDS: JIM HILL; NATE LANXON

Small but grand designs

Five small-scale models to inspire the next generation of architects, builders and engineers



KIDS' DEVELOPMENT

BRIDGE STREET TOYS TEKTÔN PLAZA

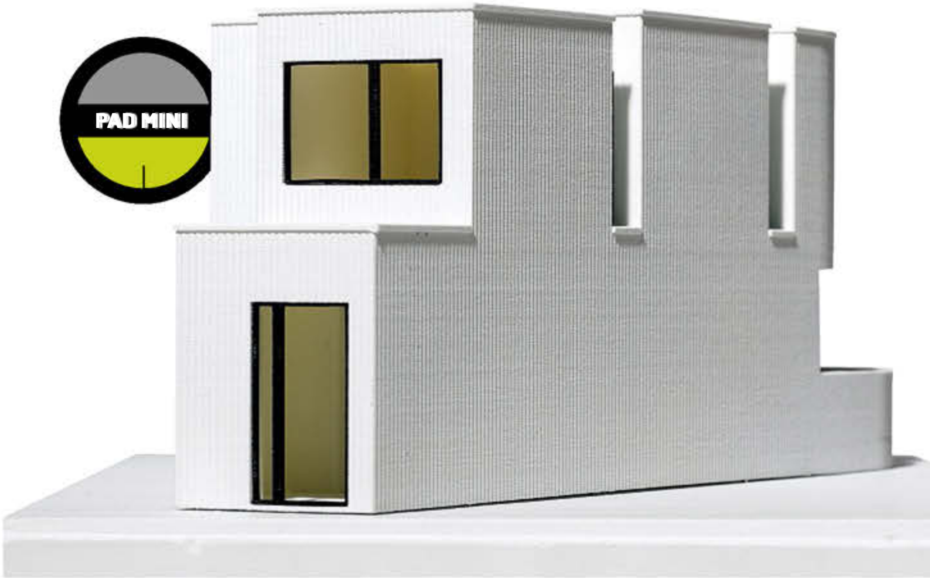
The original Girder and Panel construction kits helped inspire a generation of architects in the 60s. This modern set, featuring more than 500 plastic parts, allows budding engineers to build in the same way, while learning about torsion loads, balance and aesthetics. *$76.95 bridgestreettoys.com*

WORDS: JIM HILL. PHOTOGRAPHY: JOEL STANS; DAVE LIDWELL

PRINTED PROPERTY

CHISEL & MOUSE RYEDALE

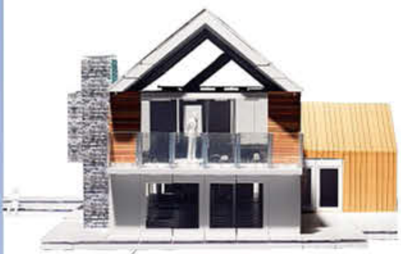
This model is based on a curiously shaped house that fits snugly at the end of a terrace in East Dulwich, south London. The small-scale version was made from polyamide, a strong yet flexible material. Having been designed using 3D software (the mouse), the components are then assembled and mounted on a plaster base (the chisel). Ryedale is a bespoke commission; the company's classic architectural models sell from £135 apiece. *£1,500 chiselandmouse.com*



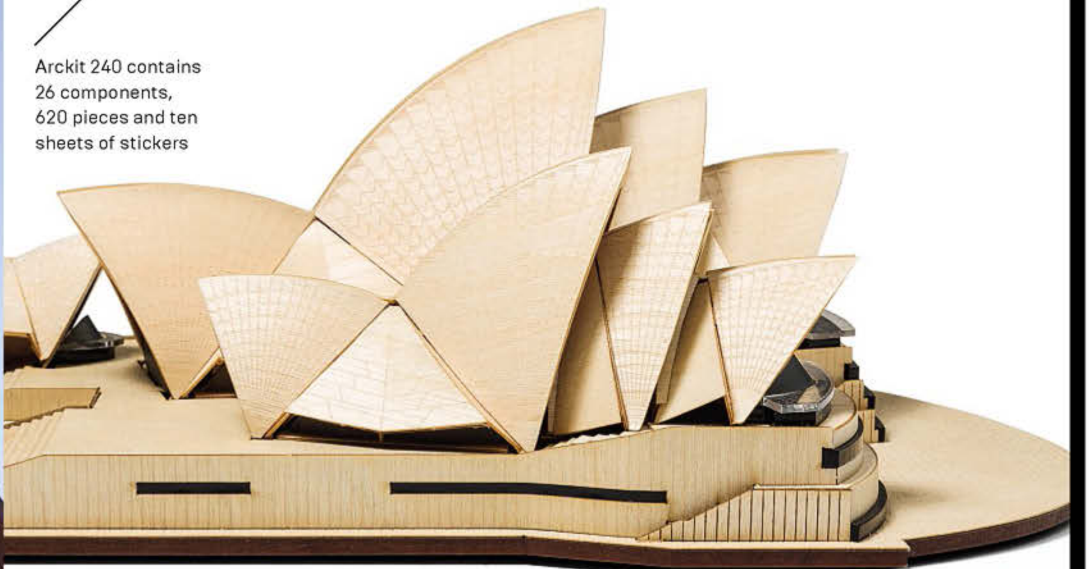
SMALL-SCALE LIVING

ARCKIT 240 BUILDING SET

Shortlisted for the 2014 London Design Awards, Arckit sets provide all the components required to make anything from a shed to a scale model of Frank Lloyd Wright's Fallingwater. Its panels, beams, windows and tiles simply slot together, making it easy to visualise complex projects. The plain white pieces can be covered with printed textures such as brickwork, available from Arckit's website. *£299 arckit.com*



Arckit 240 contains 26 components, 620 pieces and ten sheets of stickers



MODEL MASTERPIECE

LITTLE BUILDING CO SYDNEY OPERA HOUSE

The Sydney Opera House is an object lesson in modern architecture, making this birch model an educational tool as well as an attractive souvenir. Marcus Bree, its creator, spent two years using laser engraving and cutting equipment to produce the prototype's timber components for his successful Kickstarter project. The finished article will ship in January 2015. *£tbc littlebuildingco.com*

This 1:750 scale model is 210mm wide, 300mm deep and 100mm high

HOUSE OF CARD

3-D HOME KIT

This paper model's components arrive in an envelope of printed pieces that can be cut out and glued together. The sheets offer an almost unlimited variety of architectural pieces and building materials so it's possible to make an accurate copy of your own home if you wish. The reverse side of every sheet is printed with a grid to help you build to scale accurately. *£21 amazon.co.uk*

THE

FACING TOMORROW'S CHALLENGES WON'T BE EASY, BUT THOUSANDS OF YOUNG ENGINEERS AND ENTREPRENEURS ARE TAKING THEM ON

Saif Siddik
Chassis and body design

Yomna Noor El-Deen
Driver and control systems

Adam Turner
Systems designer

Abdullah Majali
Power and electronics

MAKE FUTURE

PHOTOGRAPHY: CHARLIE SURBEY

Deep in the bowels of University College London's (UCL) Engineering department, a small team of mechanical engineering undergraduates discusses regenerative braking systems, drag co-efficiencies and fuel cells. There's a buzz in the air.

In May 2015, this team will take an ultra-fuel-efficient hydrogen-powered vehicle to Rotterdam, to compete in the Shell Eco-marathon Europe. Up against around 200 teams from across Europe, UCL's Team Hydrone will attempt to travel as far as possible on the equivalent of one litre of fuel.

"I'm really looking forward to it," says Omar Gharaibeh, the team manager who is also responsible for the vehicle's body design. "We're putting a lot of energy into it, because this is our fourth-year project. We're hoping we can break a record there and set a time for UCL."

The Shell Eco-marathon is one of a number of global initiatives set up by the energy company to inspire young people into engaging with science, technology and engineering.

"By 2050, the world will be using approximately 75 per cent more energy than it does now," says Malena Cutuli, Shell's global head of brand communications and capability. "Meeting that extra demand will require a mix of energy sources – and a new generation of scientists and engineers with the passion, ideas and innovation to develop them."

With that vision, Shell has created Make the Future, a series of projects, competitions and initiatives designed to respond to our changing world by supporting, inspiring and working

Samuel Etherington
Aqua Power Technologies

Laurence Kemball-Cook
Pavegen

with young people to uncover new energy solutions. Make the Future comprises Shell LiveWIRE, an online community to support young entrepreneurs aged between 16 and 30; Shell Springboard, a funding programme for UK startups at the cutting edge of the low-carbon economy; Shell GameChanger, a programme to nurture unproven ideas that have the potential to drastically impact the future of energy; Shell Ideas360, a global competition for students to develop solutions to tackle the growing crisis around fresh water, food and energy; and Shell Eco-marathon, a series of economy and endurance races for students and pupils.

The goal, then, isn't just to inspire young would-be engineers and scientists, but to support them when creativity flourishes.

Laurence Kemball-Cook (*lower far right*) is founder and CEO of Pavegen, a UK startup making floor tiles that produce electricity from the energy of footsteps. A finalist for entrepreneur of the year at Shell LiveWIRE 2011, Kemball-Cook has since worked closely with Shell.

"Shell's support was vital in giving me the recognition I needed," he says. "It's been pivotal to growing our business globally over the last two years. We delivered projects worldwide and even managed to power a football pitch in a favela in Brazil, where we showed that the energy mix of the future can be a key way to inspire the next generation of people."

Samuel Etherington (*right*) is a finalist of the 2014 LiveWIRE programme. He received £1,000 to plough into Aqua Power Technologies, his post-university startup which harvests the power of kinetic energy in waves to create electricity. Etherington believes we have to actively encourage the next generation.

"Inspiring young students is really important," he says. "You've got to engage with students at a young age to show them how interesting the industry can be, to get them to go to university and study – but also then to carry on and go into the industry."

One group who have their sights set on careers in industry are three students from Canadian universities who won the 2014 Shell Ideas360 competition. Their design, Skywell, is a simple and accessible sail that captures fresh drinking water in the form of dew for small, rural communities. It beat around 600 other entries, each offering solutions to the growing crisis around food, energy and water. Skywell is exploring further opportunities with advice from Shell GameChanger to take the technology to the next level and perhaps even production.

Such solutions show the power of youth when energised to Make the Future. That's something we must continue to nurture.

"The world is changing," says Thijs Jurgens, vice president of innovation at Shell, "and it's critical that we work to inspire and support the next generation to take up the challenges of tomorrow. Students and young people are in the perfect position to do this, as they can be both positive and fearless."

Youth is the original disruptive technology. Let's charge it up. *makethefuture.shell.com*

WAVE POWER

Aqua Power Technologies – Shell LiveWIRE 2014 finalist

Samuel Etherington's product floats on the sea's surface and absorbs the movements of the water, converting it into energy. This energy can then be fed to shore via sub-sea cables for distribution into the national grid. "The idea came from when I was learning to kite-surf," he says. "I was out on the water really struggling to plane, constantly being hit by waves, and it was at that point that it struck home how much power there is in the sea. I was due to return to university for my final year project and thought: what about looking at wave power?"

Etherington has been inspired by technology since childhood. "Engineering has always been the family business," he says. "So I've always been surrounded by machinery, and being surrounded by it makes you want to know how it works, how you can use it and what you can make with it. I also had a really good design teacher at school. He gave me the freedom to use the machinery in open-ended projects, which allowed me to be creative."

The Shell LiveWIRE prize money helped Etherington to continue refining the system after university. He hopes it will soon help to contribute to a clean energy supply in the UK. "By 2050 I would expect the energy matrix to be at a much more even level, with CO_2 output reduced and renewable energy increased."

ECONOMY

UCL's Team Hydrone – Eco-marathon Europe entrants

Between 21-24 May, 2015, Yomna Noor El-Deen (*in the vehicle*) will don her crash helmet and pilot Hydrone – a hydrogen-fuel-cell-powered vehicle – to the greatest efficiency possible. Facing more than 200 teams from across the continent, it's hoped that this team of mechanical engineering students from UCL can wring more than 2,000km from the equivalent of one litre of fuel. But it's not just the thrill of competing that's spurring them on.

"I think its great for students to get a chance like this, because most of the work we've been doing is writing or research, and we wouldn't get the chance to see how this works in the real world."

After graduating, Noor El-Deen hopes to return to her native Egypt to work in the growing renewable energy sector.

ENERGY UNDERFOOT

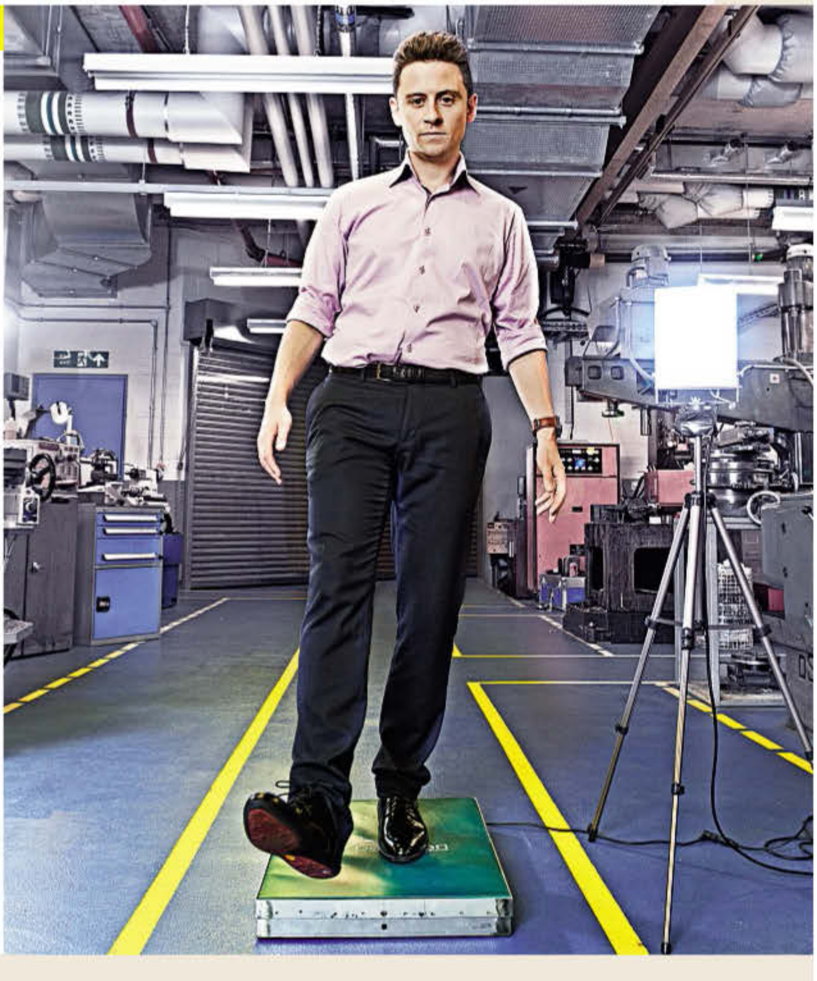
Pavegen – Shell LiveWIRE entrepreneur of the year finalist

Pavegen, run by Laurence Kemball-Cook, produces paving tiles which generate electricity from footsteps. "Our big ambition is that kinetic energy will be part of the very cities we live in," he says. "Every building, every bridge, every road will be harnessing energy from movement and be using it as an off-grid power supply in urban areas." A finalist at the 2011 Shell LiveWIRE entrepreneur of the year award, in 2014 Kemball-Cooke helped Shell to light a favela football pitch in Brazil – boosting his Pavegen technology with solar energy.

"We had 200 tiles, in additional to solar panels, underneath the football pitch, storing the energy using batteries and then powering the floodlights for the football pitch itself at night."

Kemball-Cooke comes from a long line of inventors and engineers, which – along with an engaging secondary school teacher – helped set him on the path of design and technology. But inspiration at home or in the classroom can't be relied on for every budding entrepreneur, engineer or scientist.

"Initiatives such as Shell Eco-marathon and Shell LiveWIRE, are vital in supporting new entrepreneurs," he says. "Because not only do they offer support for entrepreneurs to get to the next stage, but they also act as a way to inspire future generations and get people involved in STEM subjects."



WIRED INSIDER

Events, new products and promotions to live the WIRED life

Compiled by Ruby Munson-Hirst

1 2
3 4

1/Glenmorangie special edition Dornoch whisky

This Glenmorangie whisky is only available in select World Duty Free stores in UK airports – a percentage of each bottle sold will be donated to the Marine Conservation Society for the preservation of the Dornoch Firth where the whisky is produced.
£59.99
glenmorangie.com

2/Lyon & Lyon Six Mile Pencil set of four

Who needs fancy productivity apps? The Kickstarter-funded Six Mile Pencil from Sheffield-based design agency Lyon & Lyon revives traditional craftsmanship in the production of this most versatile creative tool – and yes, it really does last for six miles.
£8 for a box of four
lyonandlyon.co.uk

3/Ermenegildo Zegna Essenze Collection Gift Set

Founded in Italy in 1910, this menswear brand is known for its sense of luxury, craftsmanship and style. This gift set offers six 30ml bottles covering a spectrum of scent – from Sicilian Mandarin to Indonesian Oud. Look out for it in Harrods, House of Fraser and John Lewis.
£180
zegna.com

4/James Cooper's bespoke OCD artworks

Artist James Cooper creates bold works of art from unusual materials such as matchboxes, old phonecards and plastic insects. Focused on bespoke commissions, the OCD artist, as he is known, is committed to producing one-off pieces that inspire and entertain.
From £350
ocdartist.com

WIRED INSIDER'S PICK OF UPCOMING EVENTS

WIRED HEALTH

2015 will be the second year for WIRED Health, a one-day event dedicated to the future of healthcare, lifestyle and medical research. Enjoy more than 20 international speakers, plus a startup stage showcasing the sector's pioneers. *April 24, 2015, wired.co.uk/health15*

WIRED MONEY

Celebrating its third year, WIRED Money is back to disrupt the financial sector. Hosted in Canary Wharf's Level39, the event will welcome speakers and delegates from across the globe, and features pitch stages and – as always – some top-notch networking. *July 1, 2015, wired.co.uk/money15*

WIRED 2015

WIRED's flagship conference brings together innovators from the worlds of design, music, tech, science and more. The two-day event is an opportunity to experience WIRED in real life, and with over 40 speakers and 800 guests in 2014, it's getting bigger every year. *October 15-16, 2015, wired.co.uk*

WIRED NEXT GENERATION

2015 will be the largest yet for our event dedicated to 12-18-year-olds. In 2014 we welcomed guests from Rizzle Kicks to the British team building a supersonic car. Hoping to inspire and encourage, the day is full of interactivity, discussion and fun. *October 17, 2015, wired.co.uk*

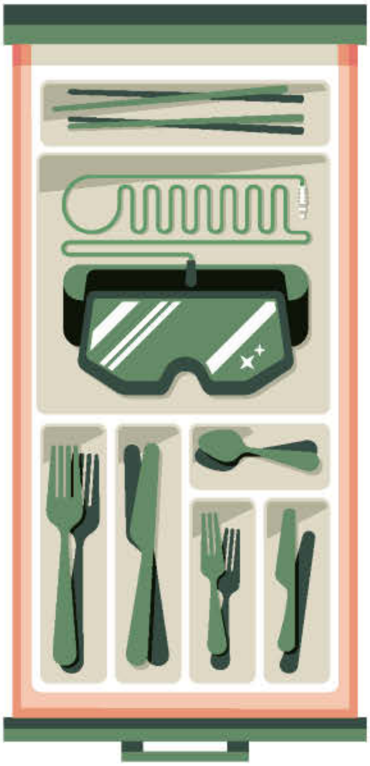
Follow us on Twitter and *Instagram*: **@WIREDINSIDERUK**

PHOTOGRAPHY: SUN LEE

IDEAS BANK

CHARLES SPENCE

Oculus Rift will make dinner taste better



According to first-century Roman gourmet Apicius, when it comes to food, "the first taste is always with the eyes". The latest neuroscience research certainly provides support for such a view, with large increases in activity being reported in a number of brain areas when participants, especially those who are hungry, view images of food.

Several decades of sensory-science research has shown that our perception of taste and flavour can be changed simply by altering the colour of food and drink. Indeed, many a wine expert has been fooled into thinking that they were drinking red wine after having been given a glass of white wine that had been coloured red. In fact, even the colour of the plate, cup, mug or can from which we eat or drink can influence our perception of flavour. In one of the world's largest multisensory experiments conducted with nearly 3,000 participants in London in May, we were able to demonstrate a 15 per cent change in people's perception of a glass of red wine (sampled from a black tasting glass) simply by changing the colour of the ambient lighting from white to red or green.

At the same time, there has been a dramatic growth in the number of people Instagramming images of their food, much to the irritation of chefs. The rise of gastroporn has also been fuelled by the seemingly endless stream of richly illustrated cookery books that no reasonable person could ever find the time to cook their way through. And then there are all those cookery programmes on television. Notice, though, how all of these cases revolve around the "eye appeal" of the food, a trend that can perhaps be traced back to the emergence of the nouvelle cuisine movement of the 60s.

Social pressure to share a meal via smartphone may interrupt the experience – yet technology also offers great potential to enhance dining. Just imagine a time in the near future, where the seas have been fished to extinction and the actual taste of that yellowfin tuna sushi is just a faint memory. An AR headset would enable the diner to view what looks like their preferred (now extinct) variety of fish while he or she eats another cheaper, non-endangered species (you can see this demonstrated in a video on WIRED's tablet edition). If, as they say, we really do eat with our eyes, then this ought to be an enjoyable culinary experience.

Now, the AR headset isn't the only way to change the appearance of food. A number of researchers have been working on presenting one dish while diners look at another, using QR codes and metacookies printed on rice paper and stuck on top of food. However, as soon as you take a bite you consume the code and the illusion is broken – OK for canapés, perhaps, but not what one wants when tucking into what appears to be a juicy steak. By contrast, the AR headset doesn't suffer from any such problems, for not only can the technology render the texture (of fish, say) beautifully (as shown in the video), but the visual impression is maintained right up until the last bite.

The AR headset can be the digital cutlery of the future, a technology that can enhance, and not simply distract from, our dining and drinking experiences in the years to come.

Charles Spence is a professor of experimental psychology at the University of Oxford. He is the co-author of *The Perfect Meal: The Multisensory Science of Food and Dining* (Wiley-Blackwell)

ILLUSTRATION: JORDAN CHEUNG

TIM LEBERECHT

Romantics, our moment is now

These days, sci-fi movies can hardly catch up with reality. We are woken up by our Pebble smartwatch, set our Fitbit, order an Uber to get to work (where we use *Klout* to gauge our influence, Meeting Mediator to manage social dynamics in meetings, and mood sensors that tell us when we're happiest). We outsource our personal relationships to apps such as *Delightful* or *HowAboutWe* (romantic concierges), *BroApp* (automated intimate texting) and *BreakUpText* or *Wevorce* (uncoupling). We rate and are rated. At night, *Shadow* tracks and analyses our dreams. Soon we will fall in love with our operating systems and drones will instantly deliver all that we desire to our doorstep.

Tim Leberecht is the CMO of design firm NBBJ and the author of *The Business Romantic* (Piatkus)

Technology has made life smoother and easier to scrutinise. But with everything outsourced and automated, familiar and convenient, where will we find those unexpected and profound experiences that punctuate our routine? Where is the unknown, where are the strangers? Where is the magic?

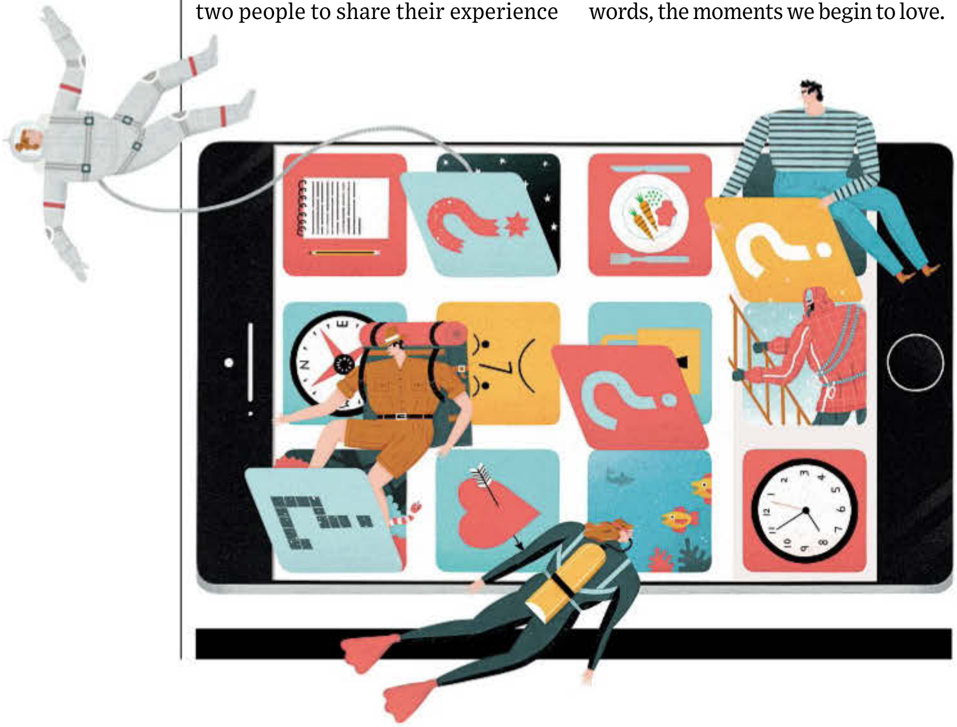
A century after the industrial age we are facing another "great disenchantment", this time caused by datafication, "filter bubbles" and (self-)surveillance. Smart algorithms and Quantified Self apps give us more control and more transparency but when everything is standardised, measured and explicitly stated, when everyone is completely predictable, we leave no room for the unreasonable and immeasurable aspects of our elusive selves. When we operate solely under the principles of efficiency and comfort, we ignore how important excess and discomfort are for creating meaning. We are indeed in the process of engineering the romance out of our lives – the last luxury in a world of utilitarian products and happiness maximisers.

There are early signs, however, that we are witnessing a backlash against the quantification of everything – and the beginning of a new romantic movement. Like the one two centuries ago – Keats, Wordsworth, Byron – that revolted against the regime of reason and rationality, the new romantics are poised to stretch our souls, defending humanity against the "second machine age". Life is not an algorithm; not a minimum viable product; not a problem seeking a solution. In fact, this time it is business and technology leading the subversive charge by creating workplace and customer experiences that encourage devotion over data, serendipity over control, delight over satisfaction and love over like.

Take the startup Surprise Industries, which offers surprises-as-a-service, or Enchanted Objects and the School of Poetic Computation, both of which instil a sense of wonder into the internet of things. Or consider apps that play with the notion of vulnerability and strangeness: *Somebody* lets you verbally deliver text messages through strangers, and *20 Days Stranger* allows two people to share their experience of the world – anonymously – over the course of 20 days. Anonymous sharing platforms such as *Whisper*, *Secret* and *Yik-Yak* trade in the currency of doubt, enabling all kinds of identity trickery and guessing games. Secret Cinema, a series of "mystery screening" gatherings, does not reveal the films it will show. In a world of always-on access and radical transparency, the things we lock away, the things that don't last, are the only remaining refuges for meaning. No wonder we turn to Burning Man, summer camps with co-workers, pop-up magazines ("just for one night"), dining-in-the-dark and intimate dinner formats such as 15Toasts, Death Over Dinner or the private-chefs-meet-diners platform Kitchensurfing, for a feeling of raw authenticity.

Knowledge is power, but not knowing might be the more powerful experience. All these formats create a new type of scarcity in the post-knowledge economy – romantic spaces that make us crave what we can't see and can't manage. They restore doubt and friction in a world of total knowledge and seamlessness. They make our lives romantic again and our workplace and customer experiences meaningful.

This is important because we are all romantics at heart. We're secretly longing for the inexplicable, the little distortions of reality, the cracks of imperfection, the detours and digressions, our exuberant passions that vie for nothing but passion itself, the moments we lose control – in other words, the moments we begin to love.



WALTER ISAACSON

Bitcoin might just save journalism

When reporting for my new book, *The Innovators,* the most frequent lament I heard from web pioneers was that they had failed to provide a platform to enable small digital payments. Ted Nelson, who conceived hypertext, believed the links should be two-way, which would have allowed a system for micropayments and royalties to accrue to content creators. Tim Berners-Lee says that he wanted to embed in a page the information needed to handle a small payment, which would allow electronic-wallet services to be built by banks or entrepreneurs. These payment protocols were never implemented, partly because of the changing complexity of banking regulations, but Berners-Lee hopes that the consortium that oversees web protocols will soon return to that task. And Marc Andreessen, who built the first popular web browser, told me: "If I had a time machine and could go back to 1993, one thing I'd do for sure would be to build in bitcoin or some similar form of cryptocurrency."

Andreessen could still get his wish. With his encouragement, people are starting to use bitcoin to develop micropayment services, such as ChangeTip and Bitwall, that have tiny transaction costs and aren't controlled by the antiquated banking system or middlemen merchants such as Amazon and Apple. They avoid the mental and financial transaction costs of the inelegant PayPal, which so far has failed to invent a frictionless micropayment system of its own.

An easy micropayment system for digital content could help save journalism by allowing people to pay a few pennies for an article or edition of a newspaper rather than having news sites become totally beholden to advertisers. As Ethan Zuckerman, an inventor of the pop-up ad, recently lamented, forcing journalists to cater to advertisers' needs was the "original sin" of the web.

Frictionless micropayments would also help producers of all different types of content, most notably individual artists, writers, bloggers, game makers, musicians and independent entrepreneurs. Ever since the Statute of Anne was passed more than 300 years ago, people who created songs, plays, writing and art have a way to get paid for copies of them. A flourishing culture ensued. Likewise, easy and frictionless coin systems that allow us to buy digital content on impulse would support journalists who want to be under obligation to their readers rather than just to their advertisers – as well as support anyone else who wants to make a living producing creative things.

Bitcoin platforms are still intimidating to people who don't want to be currency speculators, so the next big innovation will be the creation of truly simple digital coins or easy bitcoin-based systems. Those who succeed in building such services will empower creators and consumers of content and thus wrest some power from the Amazons, Alibabas and Apples. That will make them the next great digital disruptors.

Walter Isaacson is CEO of the Aspen Institute. He wrote *The Innovators: How a Group of Hackers, Geniuses and Geeks Created the Digital Revolution* (Simon & Schuster)

ILLUSTRATION: JACOB STEAD; ALEKS SENNWALD

ELDAR SHAFIR

Worrying about money can lower your IQ

Poverty means noisier and less safe neighbourhoods, greater stress, unequal access to quality medical and dental care, banking and credit, healthy foods, childcare, affordable housing, insurance and much more. Then there are society's low expectations, demeaning stereotypes, prejudice and stigma.

And it gets worse. Living in poverty requires the juggling of sporadic incomes and a perpetual struggle with difficult trade-offs. The human cognitive system has limited capacity, and focusing on the problems that come with having too little grabs substantial mental resources and leaves less mind for everything else. Pressing budgetary concerns can thus impede cognitive function in all aspects of life. In one study, shoppers contemplated everyday financial challenges that are minor hurdles for the rich but that present serious concerns to the poor. Participants were tested on two measures of cognitive capacity: executive control (the mind's ability to guide thought and action in accordance with internal goals); and fluid intelligence (analysing and solving novel problems on the fly).

In the face of modest financial challenges, the rich and the poor were equally effective. But when they were preoccupied by the financially challenging scenarios, the poor did significantly worse. When concerns of scarcity captured the

Eldar Shafir is the co-author of *Scarcity: The True Cost of Not Having Enough* (Penguin) mind, the poor had notably reduced fluid intelligence scores and exhibited diminished executive control.

This also appears to be true for people who are not "abjectly" poor, just budget-constrained. When they were preoccupied by their finances they did less well on the cognitive tests, and the effect was substantial. It was bigger than the impact of a whole night with no sleep. It was comparable to losing 13 IQ points, enough to take you from a "superior" IQ score to "average" or from average to "borderline deficient".

Studies conducted with students in top US universities and with farmers in India reveal similar patterns: people who proved highly capable in contexts of abundance became less capable in contexts of scarcity. Less-capable performance is observed not among poor people, but among people inhabiting contexts of poverty.

And inequality is likely to make all this worse. When you're poor, so many things that are easily afforded by many become temptations that must be resisted. The same good – going to the cinema, buying your child a present, having a lunch with a friend – which is a trivial consideration for those who have plenty, becomes something to be resisted when you don't have much. When there's abundance, temptation is less costly and there is less of it. When you're poor, temptation is everywhere. And no matter how many times you manage to resist it, occasionally you will give in. And it will cost you. And others will observe with disapproval and disdain.

Some inequality is unavoidable. But it would be a lot less painful if those at the bottom were not so many and not so down. Because when you're down, life is tough. Inequality makes it tougher.

MARINA GORBIS

Self-assembly schooling

Marina Gorbis is executive director at the Palo Alto-based Institute for the Future

Thomas Hunt dropped out of high school after freshman year to develop his own curriculum for studying at home, based on what he was passionate about: curing cancer. His lessons included chemistry and public speaking. He also spent time at BioCurious, a community biology lab in Sunnyvale, where he met scientists and enthusiasts. Now, aged 17, Hunt is one of the youngest 20 Under 20 Thiel's Foundation fellows, with a $100,000 (£62,000) fellowship that will allow him to pursue his dream.

We call people like Hunt "extreme learners". They aren't necessarily academically gifted, valedictorians or Mensa members. Marc Roth, for instance, earned his bona fides as an extreme learner when he was broke and living in a homeless shelter in San Francisco. Roth dropped out of high school three times and never finished his community-college education.

While at the shelter he heard about the nearby TechShop, a membership club for DIY makers and inventors. He used his last bit of money to pay for a monthly membership and took a record number of classes in everything from sewing and vinyl cutting to programming. Within two months he moved from pupil to teacher and today is running the Learning Shelter, a 90-day training programme that teaches other homeless people high-tech manufacturing skills.

What makes an extreme learner is a drive to create one's own system for learning, often "hacking" it together from a variety of existing resources, many of them outside the traditional educational institutions. Although massive open online courses (MOOCs) promised to obliterate the need for physical schools and classrooms, the discussion on the future of education is missing the much larger point. We live in an environment in which knowledge, information and tools for learning are accessible everywhere – on your laptop, tablet or smartphone. It is not just MOOCs, it is Wikipedia, WikiHow, Lynda, the *Duolingo* app for language learning, and many others. The challenge is how to entice people to dip into this knowledge.

The driver, it seems, is their social community, their peer group – places such as TechShop, BioCurious, maker places and interest communities. We know that if conversation in your children's social group is about football, the children will memorise astounding amounts of data and history about it. If the conversation was about Dickens, they would go out of their way to read Dickens. And common to all of the extreme learners we studied at the Institute for the Future is that they created or found communities and spaces for learning – although unfortunately most of these were outside traditional settings. Extreme learners found opportunities in community labs, in hackathons, tech shop, science hack-days; hardly anyone we interviewed found it in school.

Learners will increasingly be able to hack together these alternative spaces and communities to pursue their learning. What "extreme learners" are doing today on the fringes will be the norm in ten years and beyond. This necessitates a much grander rethink of institutions and pedagogy than we have so far attempted.

ILLUSTRATION: BILLY CLARK; BRENT CLARK

DHL:
ENABLING FORMULA E

As logistics partner, DHL is moving Formula E from race to race with the lowest carbon footprint possible. Relying on its network, DHL will physically transport every car, motor and tool kit. Ahead of the season's launch, DHL even reordered the race schedule for maximum efficiency. January's round-three in Buenos Aires, Argentina, will be followed by two legs in the US – to minimise distances between races.

A boost to electric cars

As the Formula E season heats up, it's the responsibility of DHL to ensure the sport rolls on as smoothly and efficiently as possible

Formula E, the electric race series, has set itself the challenge of advancing zero- and low-emission transportation. Not only do the cars run on emission-free electric motors, but the batteries powering the cars are set to be fuelled from sustainable sources.

Aquafuel Research is a British company that supplies Formula E with two mobile generators, designed to be transported to each race. These generators run on glycerine – a by-product of biodiesel production process – which release negligible emissions when used to produce electricity.

As Formula E logistics partner, DHL is transporting these generators to each race as required. DHL has also imposed a strict race order to the series, to reduce excessive air and freight transport.

In addition, the global company has limited the size and weight of each teams' transport allowance. This is reducing wastage and boosting efficiency in a number of ways.

For example, each driver is limited to three sets of the special Michelin tyres – which are effective in both wet and dry conditions – per race. With limited space, the Andretti team has created computer models to work out how best they can cram in all the race's requirements.

Want to try your hand at innovative thinking? Enter DHL's Blue Sky Transport Design Award for your chance to win £10,000. *wired.co.uk/promotions/dhl*

Powering Barca and Bullipedia

WIRED and Telefónica – it's a partnership that's provided exciting talks, collaborations and ideas. And this year was no different

Telefónica is a long-standing supporter of WIRED events and has been involved in all four WIRED annual two-day conferences since 2011. At October's WIRED2014, Telefónica's involvement was just as concerted.

On the main stage, Pablo Rodriguez (*right*), research and innovation director at Telefónica, gave attendees a crash-course in the power of data – from helping Telefónica better manage its network to enabling FC Barcelona to beat the world's best teams.

In his talk – part of The Investigators session on day two – Rodriguez highlighted comparisons between these two seemingly disparate worlds.

"The internet has evolved in a very similar way to football tactics," he said. "We used to have fixed topology. Fixed computers with one or two hops. Then the big revolution happened ten years ago with P2P networks, these complicated distributed systems that allowed a computer to perform any function, to appear and disappear anywhere in the network, creating random connections between themselves to pass the file as fast as possible."

Intrigued by this, Rodriguez began studying football tactics as if they were networks – like those that govern the internet. He found that teams with complex passing styles were also the most successful – with FC Barcelona top of the pile. He now works with the team to apply the teachings of computer science to the pitches of La Liga.

"Coaches and managers will never be replaced by computers," he said. "But computers will help. They will help in ways we've never seen before."

Later, during will.i.am's PULS smart cuff announcement, Ronan Dunne, CEO of Telefónica UK, joined the entrepreneur and musician on stage with WIRED editor David Rowan. O2 is the telecoms partner for PULS in the UK, with Dunne explaining why it was an attractive prospect.

"Will wants to break the rules, and we absolutely want to break the rules," he said. "We don't do celebrity endorsements, we've never done it. What we do is work with like-minded people and that's why we're excited about this."

The headline partner wasn't just on the main stage, either. It enabled the Test Lab together with Telefónica exhibition. Curated by WIRED product editor Jeremy White, it showcased the latest technological treats, plus the people and projects involved in Wayra, Telefónica's accelerator programme.

Smarter soccer, supporting new tech and fostering startups? We approve.

> **Coaches and managers will never be replaced by computers. But computers will help. They will help in ways we've never seen before.**

Test Lab

Curated by WIRED product editor Jeremy White, Test Lab together with Telefónica gathered some of WIRED's favourite products. From BMW's i8 hybrid supercar to the all-new ASIMO humanoid robot from Honda. Also on display were two innovative projects from Telefónica – Bullipedia and TokBox – plus Skin Analytics from its startup accelerator programme.

Bullipedia
Telefónica's collaboration with Ferran Adrià aims to map all foods and to organise all culinary knowledge.

Volution 3
Take to the skies with Parajet's new Volution 3 paramotor – lighter and with more build options than ever.

Skin Analytics
The mole-mapping service relies on algorithms to provide accurate analysis of changes in people's skin.

Oculus Rift
A VR tour of the country from the South African Tourism Board – with paragliding, shark diving and penguins.

ASIMO
Honda's humanoid robot can now climb stairs, run, serve trays of food and recognise different faces and voices.

TokBox
TokBox facilitates live, seamless video conversations – it showed off its tech with digital, remote tarot-card readings.

Der Ziesel
This single-person off-road vehicle is capable of hitting 22kph on surfaces such as mud, grass, sand and snow.

The driving of progress

AUDI FACILITATED A MEETING OF GREAT MINDS BY BRINGING TOGETHER THE WIRED2014 SPEAKERS AND INNOVATION FELLOWS – KICKING OFF TWO EXCITING DAYS OF NETWORKING, COLLABORATION AND INNOVATION

Advancement through technology, more often heard in German – Vorsprung durch Technik – neatly outlines WIRED's view of the world, and perhaps even the attitudes of the 47 speakers who appeared at October's two-day WIRED2014 event.

It's rather fitting then that Audi, whose mantra it is, hosted a dinner for the speakers at the Second Home innovation hub ahead of the event's launch. "We're welcoming some real innovators and influencers from the worlds of art, design, science and technology," said Nick Ratcliffe, Audi UK's head of marketing. This diverse group spawned some varied and exciting discussion.

"I've had conversations about quantum computing, exposing corruption and how quickly you can go about growing human bone in a petri dish," explained WIRED editor David Rowan.

Advancement through technology? Absolutely.

Clockwise from top left: guests enjoyed an apéritif ahead of the dinner; speakers were chauffeur-driven to Second Home in Audi A8 saloons; WIRED's Rupert Turnbull with dinner guests; WIRED's Sophie Hackford with 20-year-old AI pioneer Ionut Alexandru Budisteanu; attendees listen to a welcome talk from Audi's Nick Ratcliffe; Rohan Silva, cofounder of Second Home and former government technology advisor.

PHOTOGRAPHY: PETER GUENZAL

30 COUNTRIES REPRESENTED BY DELEGATES AT WIRED2014

WIRED 2014

THE OFFICIAL REPORT

BY:
STEPHEN ARMSTRONG

PORTRAIT PHOTOGRAPHY:
JAMES DAY

Magazines are an amazing way to convey the stories obsessing our team each month – but there's nothing like bringing those stories to life on a stage. On October 16 and 17 we brought together more than 50 speakers and 500 delegates for WIRED's fourth annual London conference. For two days, powerful keynotes explained the future of quantum computing, street art, personal genomics and architecture. From 23andMe's Anne Wojcicki to Zaha Hadid and will.i.am, the talks – which you can catch on the WIRED website – covered an incredible range of ideas. We also introduced the WIRED Innovation Fellows, 12 exceptional innovators from Romania to Argentina who are building the future. And for teenagers, we ran a third day for 12- to 18-year-olds, called WIRED Next Generation. Join us over the following pages and on wired.co.uk/wired2014 to experience WIRED2014. **David Rowan**

"Encrypt, find ways to encrypt: it is your duty, even if you have nothing to hide..."
Nico Sell

Yulia Marushevska

Documenting the protests in Kiev and questioning events through YouTube

"Only crazy ideas can influence the world and make our life meaningful," Yulia Marushevska told the WIRED2014 audience. She added that she was very happy to be speaking to a room full of "people with crazy ideas".

Marushevska's own crazy idea was her impassioned YouTube video, *I am a Ukrainian*, shot during the Kiev protests in February 2014, which appealed for the world to bear witness to those events. "I know that maybe tomorrow we will have no phone, no internet connection and we will be alone here," she says in the video. "And maybe police man will murder us one after another, when it will be dark here."

The video – uploaded the day after five protesters were killed, three from gunshot wounds – went viral with eight million views, and drew international pressure on the Ukrainian regime. For Marushevska, who at the time was a literature student, this helped save the protesters' crazy idea.

"Millions of people lead ordinary lives out on frozen cold streets, just to fight for their rights to live a normal life, to live a life without corruption, to have an honest government," she told the room.

The viral video gave Marushevska access to TV channels and world leaders. "I didn't sleep, I didn't have any time for anything – because people were being killed there," she said breathlessly, her voice shaking with emotion. "I was trying to share our story as far as possible because I understood that that's the only chance to be in this world against our authority and against propaganda.

"Today, we have a bigger fight," she explained. "Our former friends and neighbours attacked us, sent their troops on to our territory, occupied part of our land and started an undeclared war. It's hard to predict what will be next. But we still believe that this value of sacrificing will help us to build our country."

But what happened led to a deeper change in Marushevska: "Instead of asking myself, 'What is the sense of my life?', my question became, 'What is the sense of existing in my country?' And I realised that it's values that matter – we showed that the fight for freedom matters."

'I was trying to share our story because I understood that that's the only chance against authority and against propaganda'

YULIA MARUSHEVSKA

THE AI EXPERT

Demis Hassabis's DeepMind AI also learned how to be a *Breakout* champion in about 240 hours

Demis Hassabis

DeepMind's founder wants to rethink AI

Speaking about the chess tournament in 1997 when IBM's Deep Blue beat child chess prodigy and reigning world champion Gary Kasparov, Demis Hassabis said, "Kasparov can not only play against a machine the size of a room, but he can also talk, drive a car and tie his shoelaces".

As the founder and CEO at DeepMind Technologies – the London AI startup bought by Google for a reported £400m in January – Hassabis went on to explain that Deep Blue would be stumped if it had to play a game of noughts and crosses. "You could teach that to a person in a few minutes," said Hassabis. "But Deep Blue – you'd have to totally reprogram it."

Real machine intelligence, according to Hassabis, is "the self-learning type of AI that can learn how to master tasks directly from experiences". To test this, the DeepMind team gave their AI an old game of *Space Invaders*. "We wired it to the joystick so it knows it has 18 possible actions," Hassabis explained as a video of the AI's game play flickered on the conference screens. "Then we just give it a goal of maximising the score and that's it."

At first, the AI lost three lives immediately; but after running overnight, it was able to plan missile trajectories with precision.

"I hope these kinds of systems can help us as a society crack some of the tough problems that we would love to understand better. Climate, disease, macroeconomics, healthcare, even fundamental physics – they are all about huge amounts of data and complex systems, and maybe we're reaching some kind of ceiling in terms of things human scientists can master in their lifetimes. General learning artificial intelligence can help."

Nico Sell

Data privacy fighter

"The internet is forever – and personal conversations are not meant to be," warned Nico Sell, white-hat hacker and security activist. Speaking a week after thousands of personal *Snapchat* photographs were leaked, the co-organiser of hacking event DEFCON described the leak as "worse than herpes for those kids. We as humans need to stop making data that lives forever."

Such leaks, and the evidence of government snooping on citizens, are just the tip of the iceberg. "The NSA is the least of the threats to my friends and family," said Sell. "There are more than 70 other nation states that are very active spying, and thousands of data brokers that spend every minute of every day spying on every one of you, and that's the real problem."

Sell's tips for a safer online life included boycotting Facebook – "it was made for advertisers and for selling your information. It wasn't meant for private conversations," and sharing misinformation on your date and place of birth to hide any previous accurate posting of such details.

She also ridiculed Skype's privacy policies, claiming that some dictatorships are known to have broadcast political activists' Skype calls on TV.

$200,000 reward offered by Nico Sell to hackers

THE WHITE-HAT HACKER

Sell ran through the details of *Wickr*, her recently launched encrypted instant messenger app. *Wickr* is NSA proof, she assured the room, and allows its users to delete texts and photos already sent. There's no database – "We built a zero-knowledge system, because I'm a hacker and I know that the database will be breached," she explained. It doesn't collect metadata and has a standing $200,000 reward for anyone that can find a hole in its system. "We need to embrace hackers and say, 'We need your help and you're important to us', instead of doing the opposite," she argued.

To that end, she's set up r00tz Asylum – a hacking academy for kids where they're taught how to eavesdrop on phone calls, and turn on people's TVs and laptop cameras remotely. "This is not NSA-level stuff – we teach kids to do this in half an hour," she pointed out, to an amused chuckle from the floor.

Her crusade, she explained, was to ensure personal information "should be required to have an expiration date for any children – and, I think, people in general." To help that quest, she urged the room – "Encrypt, find ways to encrypt: it is your duty, even if you have nothing to hide..."

"We need to embrace hackers and say, 'You're important to us,' instead of doing the opposite," argued **Nico Sell**

THE AUTHOR

Elif Shafak

Embracing the written word to change the world

"Stories change, connect and help us understand and heal some of the biggest gaps in our lives..."

Can stories save the world? Elif Shafak told the audience they could. "Instead of concentrating on new technology or lamenting the demise of books, we need to bring together all the written storytelling. Because there are big cultural gaps which threaten all of us."

But, she continued, to build a story you need diversity. You also need to ensure that its benefits are widely distributed across cultures.

Although the printing press was invented in Germany in 1450, it wasn't introduced in the Islamic world until 1729 - when the first printing machine was established in Istanbul, her home town.

"There is almost 300 years between those dates - and I believe that many of the problems we face today are connected to that gap," she suggested. "I'm not claiming that the Islamic world was stagnant - the problem being its ideas were not reflected in written culture."

Although book sales are booming around the world and stories are told using every new technology, Sharaf had one big fear: "When I look at the Turkish market, between 45 per cent and 53 per cent of the books are translated from European languages," she explained. "When I look at the UK, the percentage of translated books is three to four per cent. This is a gap that we should be thinking about."

If those gaps were filled with stories, she insisted, tolerance and understanding would spread.

That is pathetic," said Anne Wojcicki. She had just asked people to put up their hands if they used online banking: most of the room did. But then she asked who accessed their health records online: not a single hand was raised. "It's one of the most important things," she said. "More important than money. But none of you have that data. And I'm passionate about you owning that information."

23andMe sequences an individual's genotype for £60. The results can be used for ancestry research and to highlight genetic health issues, revealing an individual's predisposition to more than 90 traits and conditions ranging from baldness to blindness. But in 2013, the US Food and Drug Administration warned 23andMe to stop marketing the healthcare element until it had undergone a regulatory process.

"Making these things affordable and accessible are important because we believe that understanding your genetic information is going to be good for your health," Wojcicki argued. "Mary-Claire King, the American geneticist who discovered the BRCA mutation – the breast cancer gene Angelina Jolie had – argued that all women should be able to have access to a test for the BRCA genes."

For now, 23andMe offers US customers an ancestry service while the company lobbies to reintroduce health-related results. "We have over 200 million data points on customers and the average individual who's participated in 23andMe has done over 1,330 research studies," she explained.

Wojcicki's goal remains the same, however: "We have the ability to make personal genetic information broadly available – so it should be broadly available," she insisted.

Anne Wojcicki

CEO of personal genomics company 23andMe

90+ genetic traits revealed by 23andMe's DNA test

> '[Our studies] are helping the deciphering of our code – and helping understand what's not normal and what that means'
>
> **ANNE WOJCICKI**

PHOTOGRAPHY: NICK WILSON.
STOOLS BY TOM DIXON, £160.
TOMDIXON.NET

WIRED2014: THE SPEAKERS

Back row: Nelly Ben Hayoun **Mark Chapman** Joel Jackson **Eric Ladizinsky** Nico Sell **Bruce Hood** Esther Dyson **Sam Bompas** Mariano Tomatis **Mina Girgis** Sandesh Reddy **Lee Bofkin**
Middle row: Pablo Rodriguez **Obi Felten** Jay Bregman **Simon Wheatcroft** Elif Safak **Ze Frank** Anne Wojcicki **Saul Singer** Ionut Alexandru Budisteanu **Thor Halvorssen**
Front row: John Hegarty **Jennifer Jacquet** Skylar Tibbits **Ron Arad** Uma Ramakrishnan

WIRED2014: THE SPEAKERS

Back row: Yuri Suzuki **Suleiman Bakhit** Ben Medlock **Blaise Aguera y Arcas** Andrew Hessel **Jennifer Broutin Farah** Nina Tandon **Charmian Gooch** César A Hidalgo **John Graham-Cumming** Shlomo
Middle row: His Royal Highness The Duke of York **Sugata Mitra** Zaha Hadid **Helen Arney** Stuart Turner **Dhairya Dand**
Front row: Demis Hassabis **Yulia Marushevska** Lincoln Wallen **will.i.am** Emiliano Kargieman **Rachel Wingfield**

200
The number of people in the 'granny cloud'

THE TEACHER

Sugata Mitra

Changing the way children learn

Sugata Mitra's vision of the classroom of the future is the internet in exam halls, students learning in teams and total abandonment of the "three Rs".

"If you look at the way the world has been administered over the years, it's basically been a system of empires," Newcastle University's professor of educational technology explained. "Empires need to create millions of people who are able to follow instructions, not ask questions or be creative."

Mitra spoke of his 1999 experiment, in which he fixed a computer into a wall in a Delhi slum and watched how easily local children taught themselves to use it, despite having never seen one before and understanding very little English. He used to think the kids were learning all this in spite of the lack of teachers, he explained. "But then I realised they were learning *because* of the lack of teachers."

To put theory into practice, he's founded the School in the Cloud, with over 200 "grandmothers" – people with time on their hands, a broadband connection and a willingness to help kids learn. These people offer praise, encouragement and advice, but don't teach a thing. The results, he said, were promising. And he could imagine a time when all children learned that way.

The WIRED Innovation Fellows of 2014

Emiliano Kargieman,
Satellogic, Argentina

Nelly Ben Hayoun,
The International Space Orchestra

Nina Tandon,
EpiBone

Skylar Tibbits,
MIT

Ionut Alexandru Budisteanu,
University of Bucharest

Jennifer Broutin Farah,
SproutsIO

Rachel Wingfield,
Loop.pH

Mina Girgis,
ethnomusicologist and entrepreneur

Dhairya Dand,
MIT Media Lab

Joel Jackson,
Mobius Motors, Kenya

Uma Ramakrishnan, Centre for Biological Sciences, Bangalore

Sandesh Reddy,
Kichin, India

Will.i.am chose WIRED2014 to showcase his latest venture – the PULS smart cuff. It's his stylish fashion-wearable, incorporating a curved OLED screen, speakers, SIM card, 3G, Wi-Fi, Bluetooth and GPS. Just don't call it a watch, he told the room. "'Watch' is a very limited space to innovate in," he explained. The PULS is a "standalone communication and socialisation device" based on the question: "What would Gucci, Louis Vuitton, Yves St Laurent or Chanel put tech into?"

Architect Zaha Hadid collaborated on the design. "One day I was looking at her building design, I saw her shoes, rings and her bracelets, and I thought: 'I wonder if she'd want to collaborate on our device...'" he explained.

Hadid joined him on stage to talk through her design philosophy. "I'm very attracted to ideas of technology and progress," she explained. "This has a level of complexity which is very exciting." She was inspired by her current practice – projects strong in striations and deflections – and was excited by reducing immense objects such as buildings into small haptic devices.

In the end, however, the PULS comes from the musician's twin passions – fashion and technology. "Big companies come to us all the time trying to leverage our reach to sell their product," he explained. "The amount of money they spend on R&D is around the same amount of money they pay a celebrity to promote that. So when I realised that, the world changed. That means I should take the risk to develop [a product] myself and promote it myself. The company wants me so it can have a relationship with the cool kids, but I don't participate in the upside."

The Black Eyed Peas frontman, real name William Adams, was a cofounder of Beats by Dre. Indeed, Beats CEO Jimmy Iovine credits Will with sparking the idea that became Beats by Dre. With Beats sold to Apple for a cool $3 billion (£1.8 billion), the PULS cuff proves Will's tech passion still burns.

will.i.am has chosen to work with acclaimed architect Zaha Hadid for the design of his new wearable tech

WILL.I.AM

Making hardware through collaborations

‘The amount of money they spend on R&D is around the same amount of money they pay a celebrity to promote that’

WILL.I.AM

THE ROCKET SCIENTIST

Emiliano Kargieman

The space and satellites specialist

Emiliano Kargieman has never wanted to be an astronaut – which sounds funny, he admitted, for a man whose ambition is to put almost 20 satellites into space by the end of 2015. And soon, we'll all be able to do the same.

"My history in space started from a young age when I was asked to repel an alien invasion," he joked. "But poor motor co-ordination meant I'd play *Space Invaders* for about ten seconds before losing and having to restart the game." Hacking his tiny Sinclair 2068, the young Argentinian worked out how to award himself up to 255 lives.

Working on the basis that "if you keep your hacking abilities pretty much constant, then the input you can get by hacking actually grows exponentially," he found himself working with Nasa at the Ames Research Center in California, and was stunned by the ancient tech involved in space travel.

"We were in the 21st century flying technology from the Apollo era... and I started wondering why is that the case?" he explained. "Why did the IT industry go from four interconnecting computers in 1969 to a few billion connected devices today, while we're still pretty much doing the same thing that we were doing in 1969, but we've lost the ability to send people to the Moon in the process?"

With Ames scientists, and inspired by college experiments to build satellites in a single semester, Kargieman's Argentina-based Satellogic put three satellites in the entirely unregulated low Earth orbit in 2014 – each costing just $300,000 (£190,000) to build and launch, a huge cost saving when compared to more traditional satellites' $350 million.

"The vision is to put 300 of these things up there," he told the crowd. They'll form a mesh network with satellites close to any point on the Earth pretty much all the time. Why?

"We have problems with food production and distribution, energy generation and distribution and natural resources, in particular water, with ten billion people on the planet in 20 years," he explained. "We need to be able to make decisions about these trade-offs based on data, so real-time imaging of anywhere on the planet means we can monitor violence, critical infrastructure, social conflict or the health of the planet – and solve all of those problems..."

Kargieman hopes to solve myriad problems on Earth – from space, using satellites

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THE MOVIE MAKER

Lincoln Wallen

The DreamWorks tech mastermind

80 million hours taken to make How to Train Your Dragon 2

This CTO of Dreamworks began his talk by telling a story. "The computer starts off as a friend, [but] it soon becomes the enemy and takes the artist away from what they do best – create emotion."

Ever since its creation in 1994, Wallen explained, DreamWorks has battled the problems of digitisation and art. "As it took pencils out of the hand of the artist and put them in front of a screen with a keyboard, all of their expressivity vanished," he lamented. "It's a testament to those artists that the movies we've made over the past years have been so good. They have had to fight their way through the technology to deliver the emotion you see in those characters."

Wallen went on to discuss how DreamWorks has created an artist's animation software program called Premo, so artists can return to drawing with pens and touch-sensitive displays. "Whether you're drawing things, creating entertainment for children, or designing consumer products, all of this technology will sit under this instrument," he explained.

WIRED 2014

SEE ALL THE TALKS ONLINE NOW

To view videos and highlights of WIRED 2014, visit youtube.com/wireduk

NEXT WIRED GENERATION

NEW THINKING

Our annual one-day event to inspire teenagers to think bigger

BY **KATHRYN NAVE**

If we have one goal for today, it's that when your parents or your school tell you what you should be doing with your life – you ignore them," WIRED editor David Rowan told the audience of teenagers (and their parents) at WIRED2014: Next Generation. "Work out what you want to do, and don't see limits."

The event, which took place at Tobacco Dock in east London the day after WIRED2014, featured ten workshops and 21 speakers from diverse fields including fashion, hacking, music, computer science, engineering and design.

All those onstage shared one trait – they refused to let limits define them. White-hat hacker CyFi identified her first bug at just ten years old – she is now 13. Meanwhile, dyslexic Yuri Suzuki's response to being unable to read musical notation was to create his own.

The onstage talent may have been impressive, but the speakers were just as excited. "I am thrilled to be here today, standing in front of the next generation," said actor and director Andy Serkis. "Standing in front of the people who are going to be running this country, going to be running this world – you."

A SPECIAL THANK YOU to our generous ticket donors Audi, Universal Music and EMI Music Sound Foundation, and Macmillan Science and Education

Linda Liukas

Web programmer turned children's author

Linda Liukas's deep love of programming began when she built a website about Al Gore, the then-vice president of the United States. "I was 13 and deeply in love with him," she said. "I had to learn CSS and HTML, but I was so proud.

"[Programming] is like building your own world, where you control the vocabulary, the structure and the rules."

After Liukas cofounded the successful non-profit educational initiative Rails Girls with Karri Saarinen, she decided to write *Hello Ruby*, a children's book about the fundamentals of computing. In February she raised $381,000 (£237,000) to fund the project through Kickstarter.

"Computer scientists have done an amazing job in making computers smaller," Liukas said. "[You can] learn what happens inside a computer and how they structure our world. It's not magic, it just happens really, really fast."

Ze Frank

The content king's top tips

Nobody can tell you how to get what you want from life, Ze Frank, BuzzFeed's executive vice-president of video, told the Next Generation audience – least of all him.

"Some of you are searching for a mantra that will carry you through your creative life. But any sort of advice that I could give you now is probably not even going to apply to your career, because everything will have changed by then," he said.

The problem with a successful person providing a key principle to their success is that it's a product of hindsight bias, Frank explained.

"You can't be anxious about not having this one thing that's going to carry you forward. You're a complicated individual. And you will change over time."

THE ACTOR

Andy Serkis

Performance-capture artist turned director

Actor and director Andy Serkis wants to use technology to revolutionise an ancient craft. And, he explained, it all began with one "three-and-a-half-foot-tall ring junkie". In his role as Gollum in Peter Jackson's *Lord of the Rings* trilogy, Serkis was a pioneer in the use of performance capture, in which every detail of an actor's movements is tracked via a special suit, then transposed on to digital avatars.

"I believed Gollum was a complete anomaly, and I would probably never encounter this way of working again."

Then, Peter Jackson asked him to play King Kong. "I thought, 'That's a 25-foot gorilla, how the hell am I going to do that?'" Serkis recalled. "But he said, 'We'll just use performance capture.' That was the big epiphany." Serkis has led an entire performance-capture army as Caesar in *Dawn of the Planet of the Apes*, and cofounded London-based digital studio The Imaginarium, where he's using the technology to make a CGI version of George Orwell's *Animal Farm*.

"We are taking actors and making them into all sorts of quadruped animals. This is the death of typecasting. This is the end of stereotyping. If you can get inside the mind of the characters, then it doesn't matter how big you are, what colour your skin is. If you've got the ability to lose yourself within a character then you can do anything."

Fleur De Force

Beauty vlogger

Fashion and beauty YouTuber Fleur De Force has three successful channels with over 1.7 million subscribers split between them. She's appeared on the reality TV show *Project Runway,* interviewed Kylie Minogue, Pixie Lott and Lily Allen, and travels all over the world working with international beauty brands. "The best thing was meeting Taylor Swift," she said.

Yet when she began, it all seemed like just a slightly strange hobby. "I started five years ago when it wasn't as normal as it is now to do YouTube," she said.

When she started, De Force told only her mother and boyfriend. "I was so nervous about what they would think, but then all these other people started watching it and it actually went down really well," she said. "When I left university, I thought, 'I need to get a normal job, but if I do I'll have to stop dedicating so much time to YouTube.' So I made the decision to give myself six months to try really hard and see where this could go."

As her views rose, so De Force expanded her YouTube empire into vlogging about her day-to-day life. "You don't really realise how much information you're giving away until random people say, 'Oh, I saw you and your mum eating'. Most of the time, though, I do share pretty much everything."

THE YOUTUBER

THANKS TO ALL OUR WIRED NEXT GENERATION SPEAKERS:

Tim Peake
Helen Sharman
Andrew Henderson
Jordan Stephens and Harley Alexander-Sule (Rizzle Kicks)
Fleur De Force
Mark Chapman
Ze Frank
Alex Allmont
Roma Agrawal
Jack Cator
Helen Arney
Darcus Beese
Yonatan Raz-Fridman
Patrick Stevenson-Keating
Suli Breaks
Brooke Roberts
Beth Reekles
CyFi
Ryan Genz & Francesca Rosella
Yuri Suzuki
Ionut Alexandru Budisteanu

Student startups

At October's WIRED Next Generation, Barclays hosted two workshops aimed at introducing young entrepreneurs to industry

"First off," said Ze Frank, vice president of video at BuzzFeed. "How many of you here are actually thinking of starting your own business?"

With the confidence that only teenage years can supply, a flurry of arms reached up. This was a fired-up audience replete with ideas, ambition and perhaps a little inexperience.

Barclays' A-Z of Launching Your Own Startup workshop saw a select group of young, would-be entrepreneurs sit down to lunch with mentors from across different disciplines to talk through the obstacles and rewards that lie in store for those planning on starting their own businesses.

With practical advice such as when to seek funding and when to bootstrap budgets from scratch, alongside psychological preparation – such as how to keep calm and carry on when you have only your self-belief to drive you forward – the panel walked the students through their own successes and mishaps.

Chaired by WIRED associate editor Madhumita Venkataramanan, a wealth of experience was divulged by the panel, which comprised Mutaz Qubbaj, founder of financial well-being startup Squirrel; Jack Cator, founder of internet privacy platform Hide My Ass!; Francesca Rosella and Ryan Genz of fashion company CuteCircuit and, of course, viral video veteran Ze Frank.

The most common among startup pitfalls? Giving up too soon. If nothing else, the business leaders of tomorrow will have learnt to trust themselves when others doubt them. Everyone needs to make that leap of faith at least once. *barclays.com/entrepreneurs*

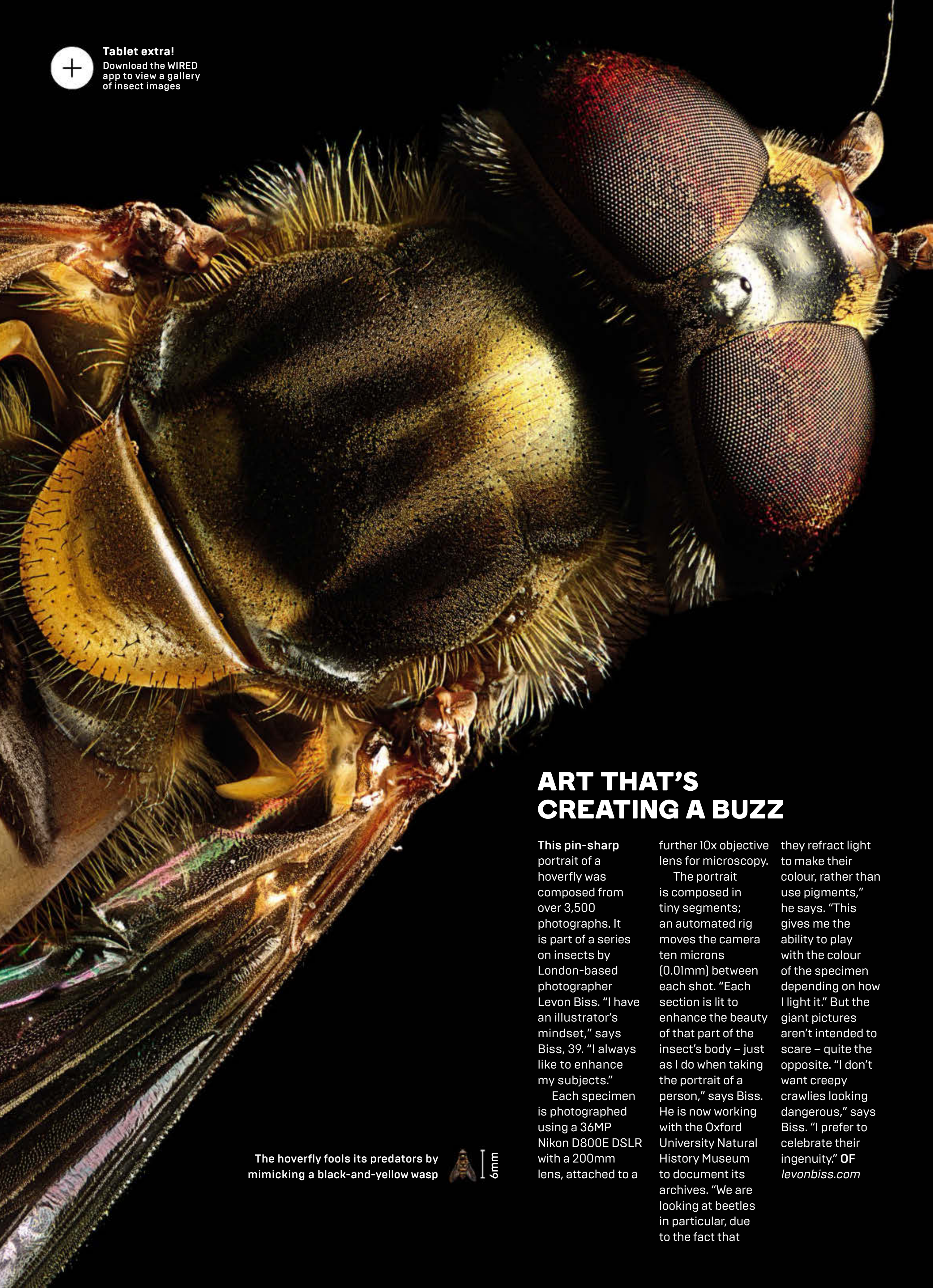
HOW TO:
BECOME A SOCIAL ENTREPRENEUR

Barclays' second workshop introduced teenagers to the concept of social enterprise. With a panel of social entrepreneurs in fields as diverse as ethical textiles, low-cost space exploration and using robots to reveal the lives of plants, the students were able to explore the different possibilities of social enterprise – such as traditional fundraising or even crowdfunding. They then broke into groups to conjure up new ways of increasing awareness in the mentors' industries. Judging by their ideas, the future of social enterprise is bright.

PHOTOGRAPHY: LEON CSERNOHLAVEK; CARSTEN WINDHORST

PLAY

Tablet extra!
Download the WIRED app to view a gallery of insect images



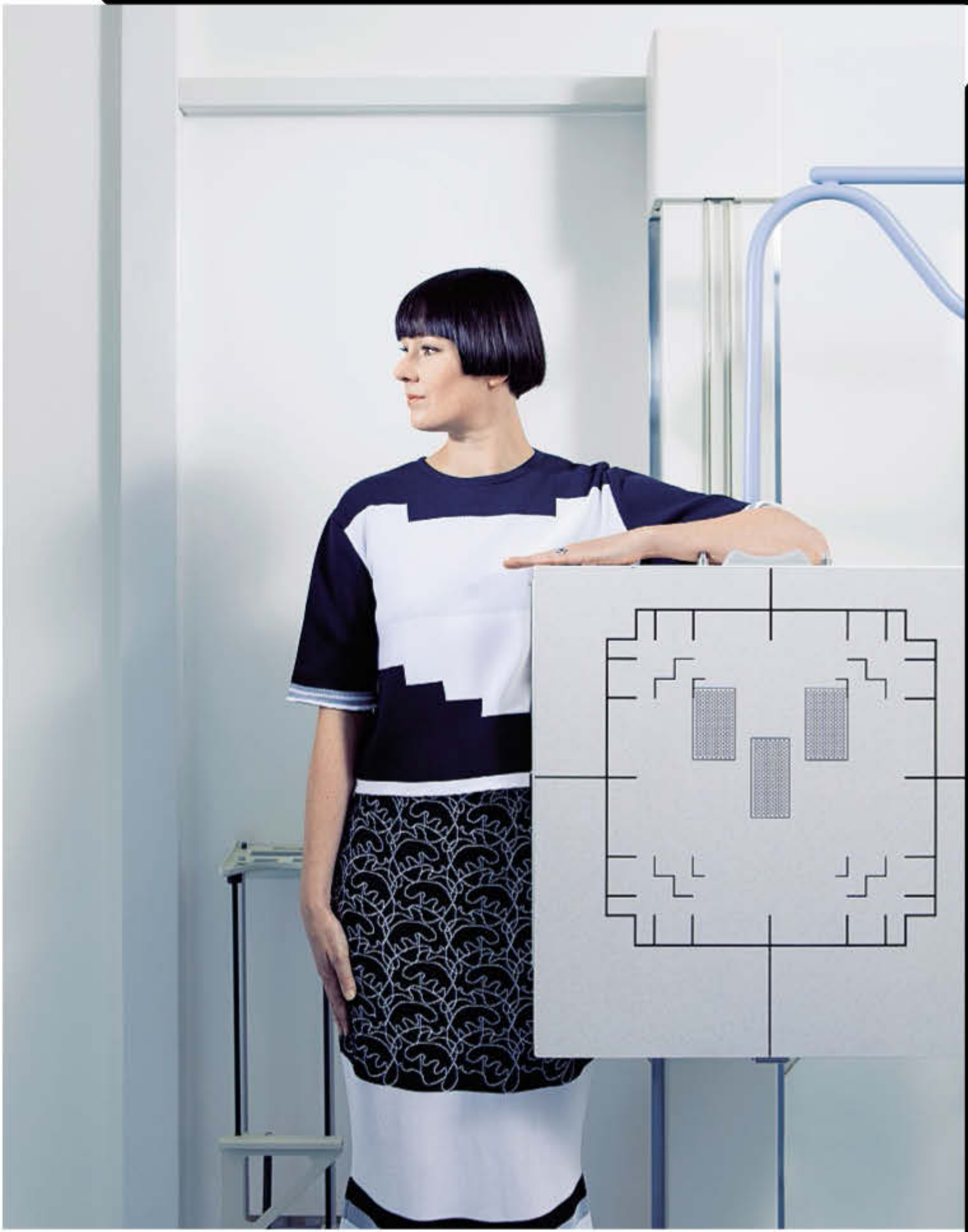
The hoverfly fools its predators by mimicking a black-and-yellow wasp

ART THAT'S CREATING A BUZZ

This pin-sharp portrait of a hoverfly was composed from over 3,500 photographs. It is part of a series on insects by London-based photographer Levon Biss. "I have an illustrator's mindset," says Biss, 39. "I always like to enhance my subjects."

Each specimen is photographed using a 36MP Nikon D800E DSLR with a 200mm lens, attached to a further 10x objective lens for microscopy.

The portrait is composed in tiny segments; an automated rig moves the camera ten microns [0.01mm] between each shot. "Each section is lit to enhance the beauty of that part of the insect's body – just as I do when taking the portrait of a person," says Biss. He is now working with the Oxford University Natural History Museum to document its archives. "We are looking at beetles in particular, due to the fact that they refract light to make their colour, rather than use pigments," he says. "This gives me the ability to play with the colour of the specimen depending on how I light it." But the giant pictures aren't intended to scare – quite the opposite. "I don't want creepy crawlies looking dangerous," says Biss. "I prefer to celebrate their ingenuity." **OF** *levonbiss.com*



FASHION FOR EVERY BODY

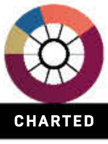
DESIGNER BROOKE ROBERTS'S IDEAS COME FROM WITHIN – THE BRAIN, INTESTINE, BONES...

Brooke Roberts has always found brain scans to be beautiful – so she decided to wear them. The London-based radiographer-turned-designer takes CT and MRI scans from friends and turns them into science-inspired womenswear.

Roberts, 39, assigns every pixel in a scan to a stitch using design software. A 1,000-needle Stoll digital knitting machine follows the pattern in merino wool and man-made yarn. The first time she tried it, Roberts spent two days assigning stitches before realising the scan resolution was too high – the finished product would have been 10m wide. "I wasn't familiar with programming," she says. "But I'm an experimenter."

Roberts also combines the scanned prints with other visual references (for her spring/summer 2015 collection, 8-bit video games and comic-book icon Tank Girl), and often seeks inspiration in unusual anatomy found in public resources, such as the Allen Institute's Brain Atlas (Paul Allen, Microsoft's cofounder, is a fan). "Sometimes you get interesting orthopaedic presentations," she says. "But for the most part I like soft tissues." A cardiac radiography specialist by day, she plans on experimenting with the "sprawling, filament-like" textures of the heart, and she has bookmarked a particular brain scan that looks like Gene Simmons's KISS makeup.

Not every body part lends itself to fashion, however. "The abdomen," she says with a shudder. "[Scanned], it's loopy and bulbous. I think it's partly understanding it that's the problem. A designer friend thought it looked like clouds. I just see the barium." **Liat Clark** *brookeroberts.net*



CHARTED

Reasons to play *Grand Theft Auto V*'s HD remake

4K graphics on high-end PCs

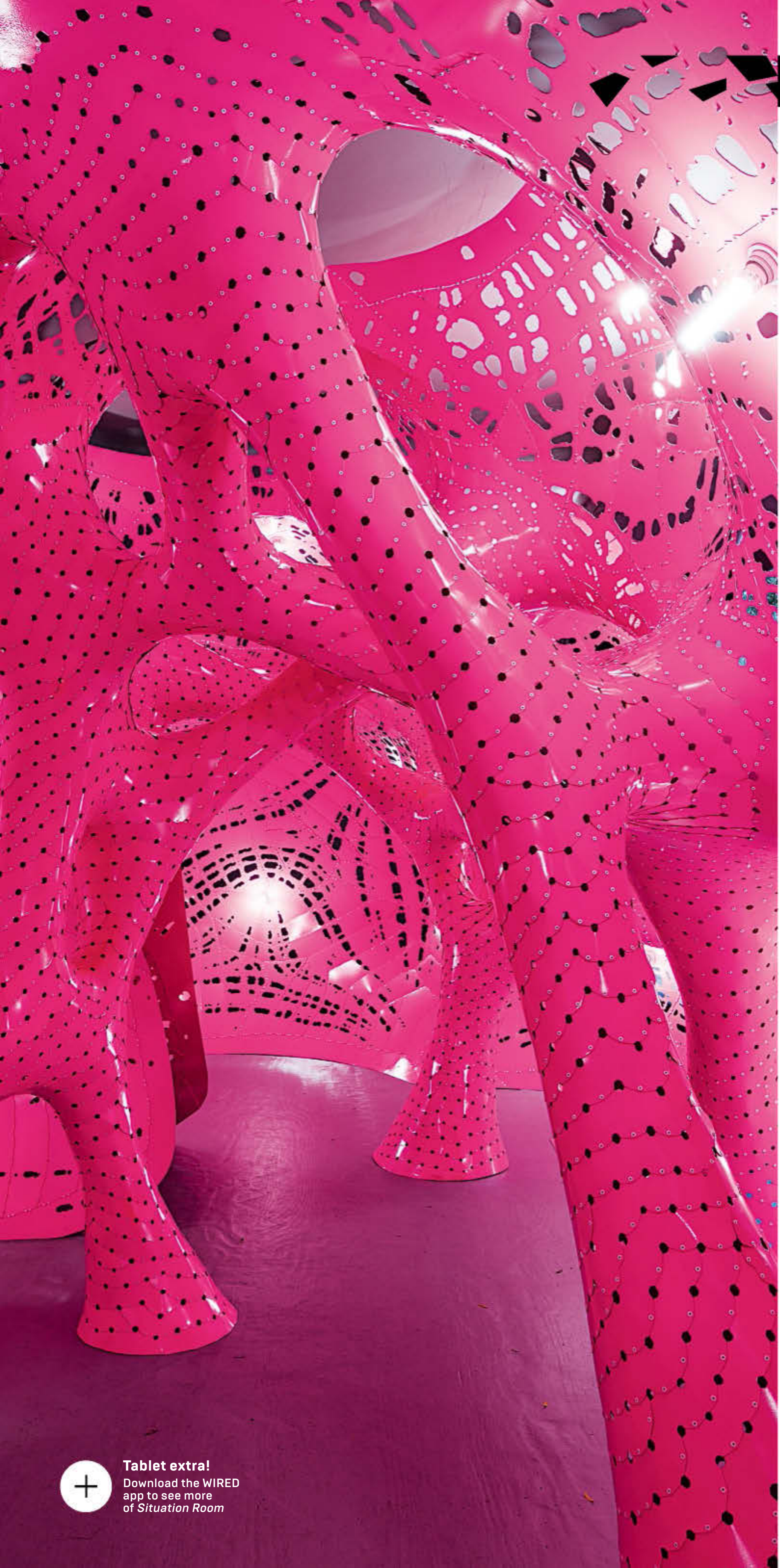
Several hours of exclusive content

First-person POV

Heist missions promised, but never delivered, in the original (0%) (they're still not included)

The lack of original, blockbuster games on current-gen consoles

PHOTOGRAPHY: MIGUEL DE GUZMÁN; DAVID VINTINER. HAIR AND MAKEUP: CAROLINE SIMS



Sounds like pink metal

ARTIST JANA WINDEREN PLAYS THE MUSIC OF THE DEEP IN A CORAL CAVE

Jana Winderen uses eerie sounds to transport her viewers to spectacular worlds. Take *Situation Room* (*left*) – a hot pink collaboration with the architect Marc Fornes, which is currently installed in New York's Storefront for Art and Architecture. "I wanted an immersive environment where the physical sound of the structure would be part of [the show]," says Norwegian-born Winderen, 49.

Fornes used generative computation to design the structure's 20 interlacing spheres, fused together using Boolean mathematics. It uses 1,673 hand-connected aluminium panels; ten transducers vibrate the structure's surface to create Winderen's surreal soundtrack.

"At high frequencies," says Winderen, "the structure started to rattle, because of all the rivets and joints." So she settled on the fricative sounds of water-borne insects such as water boatmen. "They sound like crickets, and use stridulation [rubbing their limbs together] to make noise," she says. The resulting music was combined with electronic sounds. Such creations reflect Winderen's desire to make people experience the natural world – particularly underwater – in new ways. "It's an audible landscape," she says. **OF** *janawinderen.com*

The left side of this CGI model shows stress flow; the centre, the density of the structure; and the right, its porosity

Tablet extra!
Download the WIRED app to see more of *Situation Room*

ILLUSTRATION: THE RED DRESS

FALLEN LONDON RIDES AGAIN

Failbetter Games' browser-based *Fallen London* has built a cult following. "It's a children's ghost story for adults," says the UK studio's chief narrative officer Alexis Kennedy, 42. Inspired by the developer's Greenwich location, this month's sequel *Sunless Sea* takes the game on to open water.

As a ship's captain, the player switches between exploring the "Unterzee" – a vast underground lake – and *Fallen London*'s multiple-choice narrative system. The latter now contains more than a million words of content; players can use the open StoryNexus engine to create their own adventures (which spawned a prequel, *The Silver Tree*).

Although the two games are separate, Kennedy created subtle story connections which don't just enrich the narrative, but encourage players to explore the wider universe. The result: Failbetter found that early access also tempted first-time explorers to *Fallen London*. "When you begin *Sunless Sea*, you're in the port," says Kennedy. "But people want to see what's in the city, too."
Daniel Nye Griffiths
Sunless Sea *is out in February for PC and Mac failbettergames.com*

PHOTOGRAPHY: LEVON BISS. ILLUSTRATION: ROBERT BALL

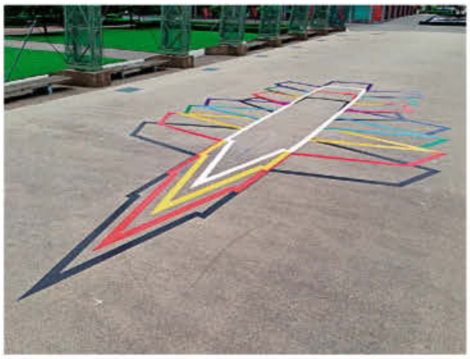
Drawn warfare

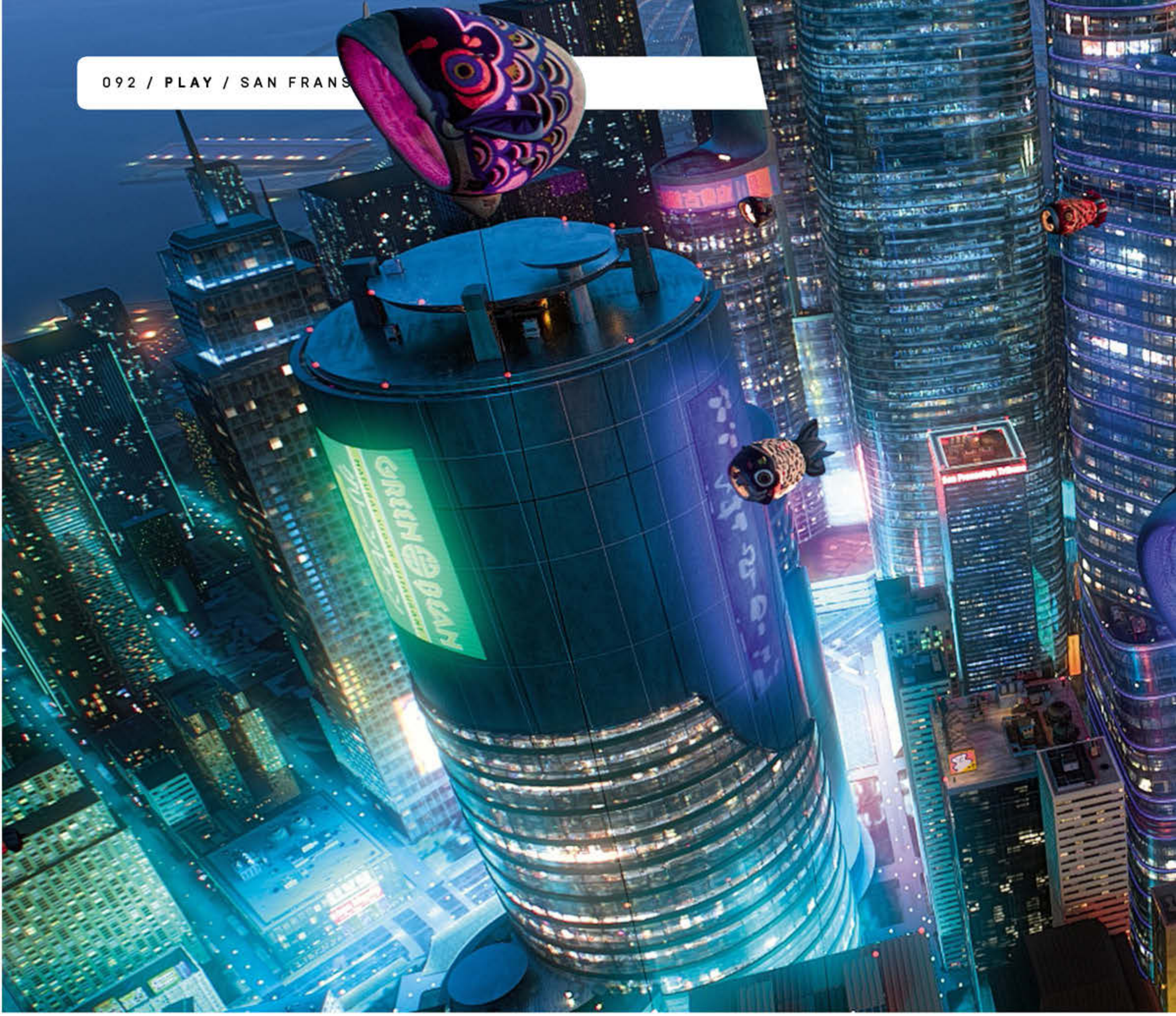
JAMES BRIDLE IS ON A MISSION: TO HELP YOU VISUALISE DEADLY DRONES

James Bridle wants to reveal the invisible. "Our world doesn't look dramatically different to how it did 20 years ago," says the London-based artist. "It's hard to point at the internet. But for me it's essential to do that because without it we have no understanding of how our world really works." In the MQ-1 Predator drone, Bridle, 34, finally found something he could point at. "The drone is an avatar of this whole network of the internet and us," he explains. "They're these large, highly connected physical objects, yet they're rarely seen." Bridle (*above*) realised he didn't even have an idea of their size. "I literally went out into the car park of my studio and sketched out the outline," he says. This led to his *Drone Shadows* project, which had him drawing the looming, sinister scale-diagrams of the Predator at locations all over the world, including outside the White House. Other 1:1 outline projects include the *Rainbow Plane 001* at Farnborough Airfield, which mimics how the different wavelength sensors used to create satellite imagery produce the appearance of a multicoloured trail behind the airborne craft.

With his latest work *A Quiet Disposition*, Bridle comments on the US military's Disposition Matrix, a secretive database used to generate kill lists. Bridle's program scours the web for names and places mentioned alongside drones, adds them to his own database and pulls out links between them. The result is vast and highly error-prone. Swiss figure-skating champion Patrick Meier appears prominently, for example – the program confused him with a UAV researcher of the same name. "The idea is to demonstrate how flawed that data-driven approach to decision making can be," say Bridle.
Kathryn Nave *shorttermmemoryloss.com*

Bridle's *Rainbow Plane 001* at Farnborough airfield, 2014





Bright lights, big (hero) city

For Big Hero 6, Disney redesigned its animation toolkit to enable images to be illuminated from all angles

How do you follow an Oscar-winning, $1 billion (£620m) smash like *Frozen*? For Disney Animation Studios, the answer was simple: aim bigger. *Big Hero 6*, out January 30, marks its most visually ambitious film yet. Adapted from an obscure Marvel Comics franchise, the film follows a boy called Hiro and his inflatable nurse-robot, Baymax, who unite with friends to assemble their own ragtag team of superheroes.

"Each film has its own unique needs, whether it's *Frozen* with snow and ice, or having to build an entire city," says Disney chief technology officer Andy Hendrickson, 49. *Big Hero 6*'s setting, San Fransokyo – a vibrant Tokyo/San Francisco mashup – is vast, containing 83,000 buildings, 215,000 trees and 100,000 vehicles. "It's so visually rich," he says. "This film has three times more objects

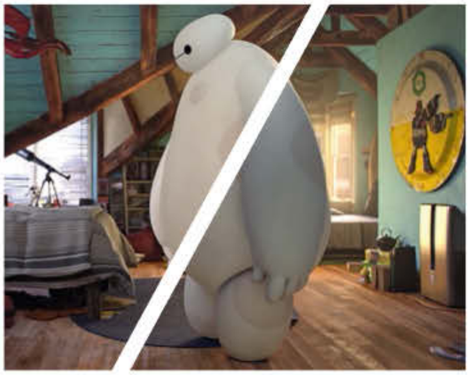
Tablet extra!
Download the WIRED app to view the trailer for *Big Hero 6*

in it than our last three films [*Tangled*, *Wreck-It Ralph* and *Frozen*] combined. We had to design new methods to deal with all that complexity."

Chief among the new animation tools created for the film is Hyperion, Disney's new custom-built digital tool for lighting. The renderer allowed the animators to create global illumination, whereby light bounces off and scatters through surfaces. Where light once might have been laboriously animated for a single bounce, Hyperion automatically simulated up to 20 bounces per scene, resulting in spectacularly nuanced images. "We were able to let light filter through the city, through windows, off buildings," says Hendrickson. "It gives a softness to the light you can't match in any other way. The results are pretty dramatic."

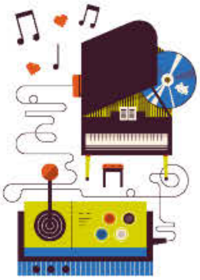
Rendering so much detail requires a huge amount of power, so Hendrickson and his team built a 55,000-core supercomputer across four locations to manage the heavy workload. Using another new piece of Disney-built software called Coda, the computer processed more than a million computation hours every night for several months to render the film. "This film is a big milestone for us," says Hendrickson. "You can watch it multiple times and still see new things." **OF**

Big Hero 6 *is out on January 30, movies.disney.com/big-hero-6*



Above: San Fransokyo at night. *Left*: *Big Hero 6* rendered with animation tool Hyperion (*on the left side*) compared to previous lighting

ILLUSTRATION: JAMIE JONES



Piano scores

Yuval Kaminka wants to make learning a musical instrument as easy as playing *Guitar Hero*. "The inspiration came from one of my nephews," says the cofounder and CEO of Tel Aviv-based startup JoyTunes. "Why was he so passionate about the Wii, but fought against the piano?"

The answer: it's not fun to be bad at something. "Most people drop out of playing an instrument before they reach an aptitude where it becomes enjoyable," says Kaminka, 33. So JoyTunes' iOS app *Piano Maestro* gamifies the experience, using skill challenges, scores and achievements to teach students basics like sight-reading, rhythm and technique. Learners play along in time with one of 1,000 songs; the app uses an iPad's mic and audio recognition to identify how well they're playing.

Most users pay a subscription fee, but JoyTunes is making the app free for teachers and students. "We're seeing it being used as a primary or even the sole method for teaching," says Kaminka.

The results are impressive: "We've found that kids are practising at home much more frequently." **OF** *joytunes.com*

The power of networking

AT WIRED2014, SESSION PARTER INTEROUTE HELD A VIP BREAKFAST DISCUSSION ON THE FUTURE OF THE CLOUD

Machine learning, the internet of things, ever-increasing connectivity, wearables. They're some of the most disruptive forces in the world and they all rely on one thing: the cloud.

On the morning of WIRED2014, Interoute – owner operator of Europe's largest cloud services platform – held a panel discussion with event delegates to map out the future of the technology. Chaired by WIRED's Sophie Hackford, the panel included Google Ventures' Tom Hulme, Interoute CTO Matthew Finnie, WIRED contributor Daniel Nye Griffiths and WIRED2014 Innovation Fellow and speaker Emiliano Kargieman, who is CEO of the aerospace company Satellogic.

"The tipping point is now," says Matthew Finnie. "The debate is not 'am I going to use the cloud?', because you are. The debate is 'how am I going to use it and how will it work for me?'"

It's been a democratising force – allowing startups to scale on demand and on a budget. The Networked Cloud has heralded an era focused on user experience and design, having taken care of the tricky plumbing of infrastructure. It's also empowering the developing world, where such infrastructure is poor. In short, cloud networks are powering tomorrow. So, what will you build?

cloudstore.interoute.com

IDEAS SHARING

Tom Hulme, Google Ventures
"The cloud gives us new capacity, which would have been too expensive in the past. And it gives us flexibility. A startup is as good or as bad as its flexibility."

Matthew Finnie, CTO, Interoute
"We want to enable people to take their ideas, transform their infrastructure, fix how they're doing things and take it to the next level... in the most efficient way."

DATA STATION

Interoute's Test Lab installation
How do you convey the speed of Europe's largest network to more than 500 delegates at WIRED2014? A race, of course. In the Test Lab, Interoute challenged guests to pick up a controller and race a virtual car around a short circuit faster than Interoute could transfer a file across Earth. The result? The machines win this round. Better luck next time, guys.

PHOTOGRAPHY: PETER GUENZAL / LEON CSERNOHLAVEK

ICICLE WORKS

MAD ARCHITECTS FIND THE PERFECT FORM FACTOR IN THE SHAPE OF FROZEN LIQUIDS

Chinese architect Ma Yansong may specialise in skyscrapers, but he thinks like a gardener. "There are layers of philosophical and cultural meaning to a garden," says the founder of Beijing-based MAD architects. "What if we treated these towers like mountains in a landscape?"

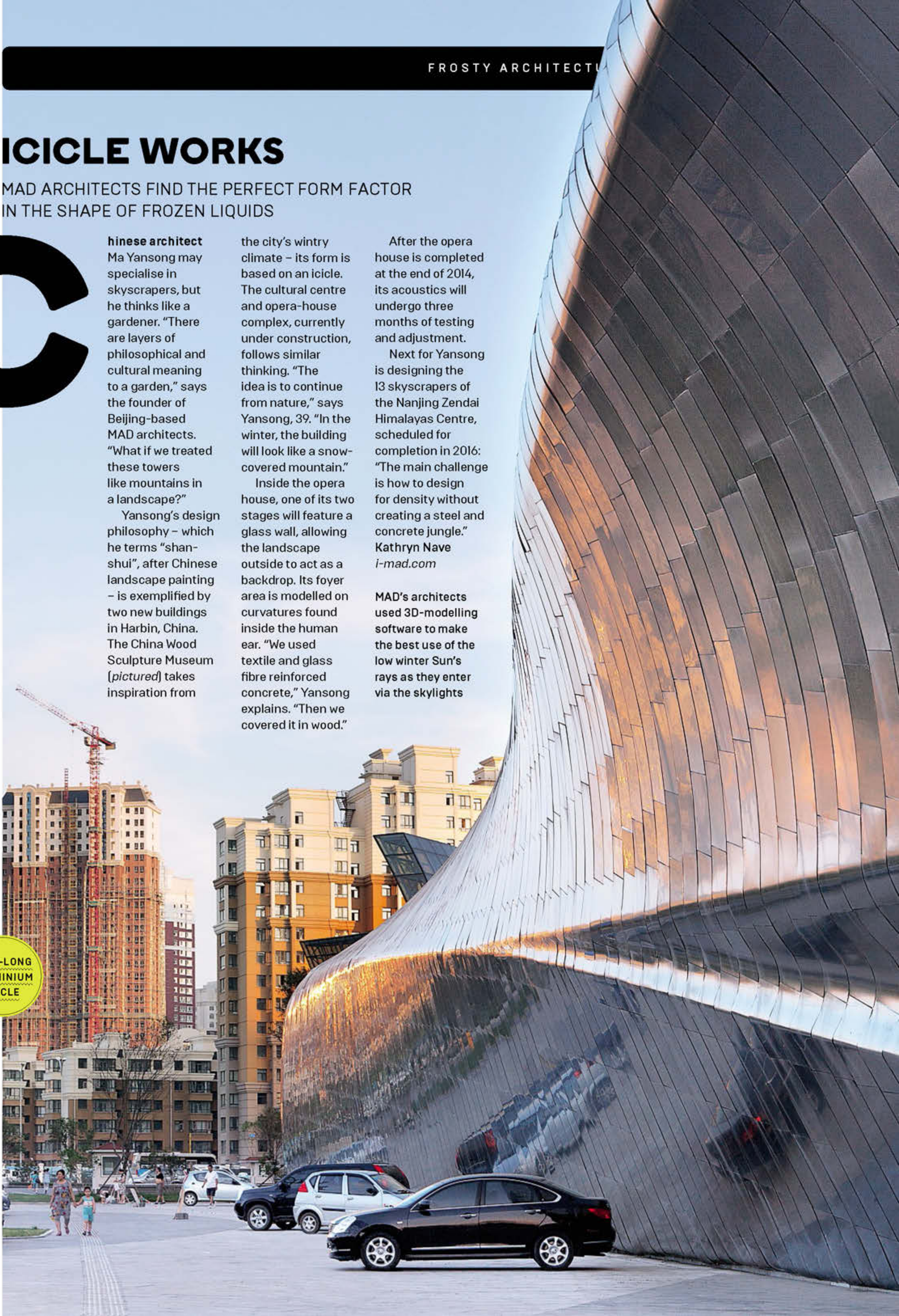
Yansong's design philosophy – which he terms "shan-shui", after Chinese landscape painting – is exemplified by two new buildings in Harbin, China. The China Wood Sculpture Museum (*pictured*) takes inspiration from the city's wintry climate – its form is based on an icicle. The cultural centre and opera-house complex, currently under construction, follows similar thinking. "The idea is to continue from nature," says Yansong, 39. "In the winter, the building will look like a snow-covered mountain."

Inside the opera house, one of its two stages will feature a glass wall, allowing the landscape outside to act as a backdrop. Its foyer area is modelled on curvatures found inside the human ear. "We used textile and glass fibre reinforced concrete," Yansong explains. "Then we covered it in wood."

After the opera house is completed at the end of 2014, its acoustics will undergo three months of testing and adjustment.

Next for Yansong is designing the 13 skyscrapers of the Nanjing Zendai Himalayas Centre, scheduled for completion in 2016: "The main challenge is how to design for density without creating a steel and concrete jungle."

Kathryn Nave
i-mad.com



MAD's architects used 3D-modelling software to make the best use of the low winter Sun's rays as they enter via the skylights

196M-LONG ALUMINIUM ICICLE

PHOTOGRAPHY: XIA ZHI

Download this table

HOW ONE UK STARTUP IS RETHINKING FLAT-PACK – AND BUILDING A GLOBAL NETWORK OF MAKERS

Half Sheet Table designer, Lynton Pepper

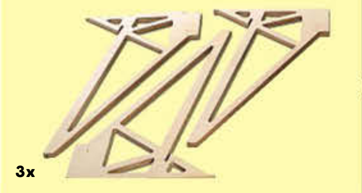
OpenDesk is taking flat-pack furniture open source. Just pick a design, such as the Half Sheet Table (*pictured, left*), from its website, download and tweak the CAD file, and OpenDesk will find a local fabricator to mill and send you the cut-out parts. (Or, if you happen to own a computer numerically controlled milling machine, you can make the pieces at home.)

"We wanted to explore the idea of open making, by connecting designers and makers, [and removing] middlemen," says cofounder Nick Ierodiaconou, 33. Founded in 2013, London-based OpenDesk was spun out of 00, the British design and architecture collective behind the open-source WikiHouse project (WIRED 02.12). The vision: to make the physical world more like software – but rather than developers modifying code, it's designers and makers sharing and tweaking physical objects. The result is "somewhere between GitHub and Airbnb for furniture," says Ierodiaconou.

More than 150 makers have already signed up to OpenDesk in 38 countries. "It allows for furniture to be made locally all around the world," Ierodiaconou says. "In one case, we had a client in east London. We found a nearby workshop, got the order made, finished and shipped within a five-mile radius [of them] – but the design they chose came from São Paulo."

At present, each OpenDesk order is processed on a case-by-case basis; the company will roll out a full online marketplace in 2015. And although the mostly modern, functional designs are currently limited to plywood ("it's stable, predictable and universal") OpenDesk hopes to add other materials soon. "It's not so much about saying we're going to topple IKEA," says Ierodiaconou. "It's about recognising that the web is unlocking this completely new supply chain." OF *opendesk.cc*

TABLE OF CONTENTS



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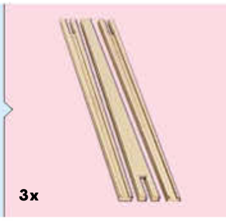

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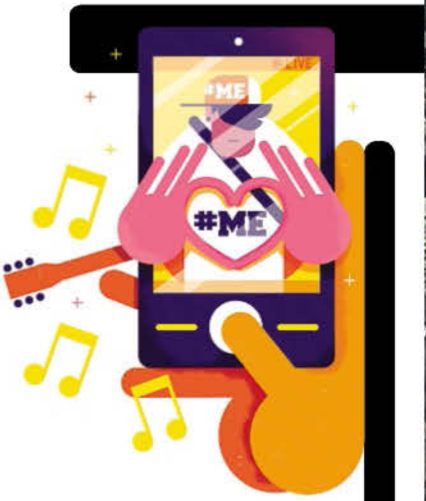


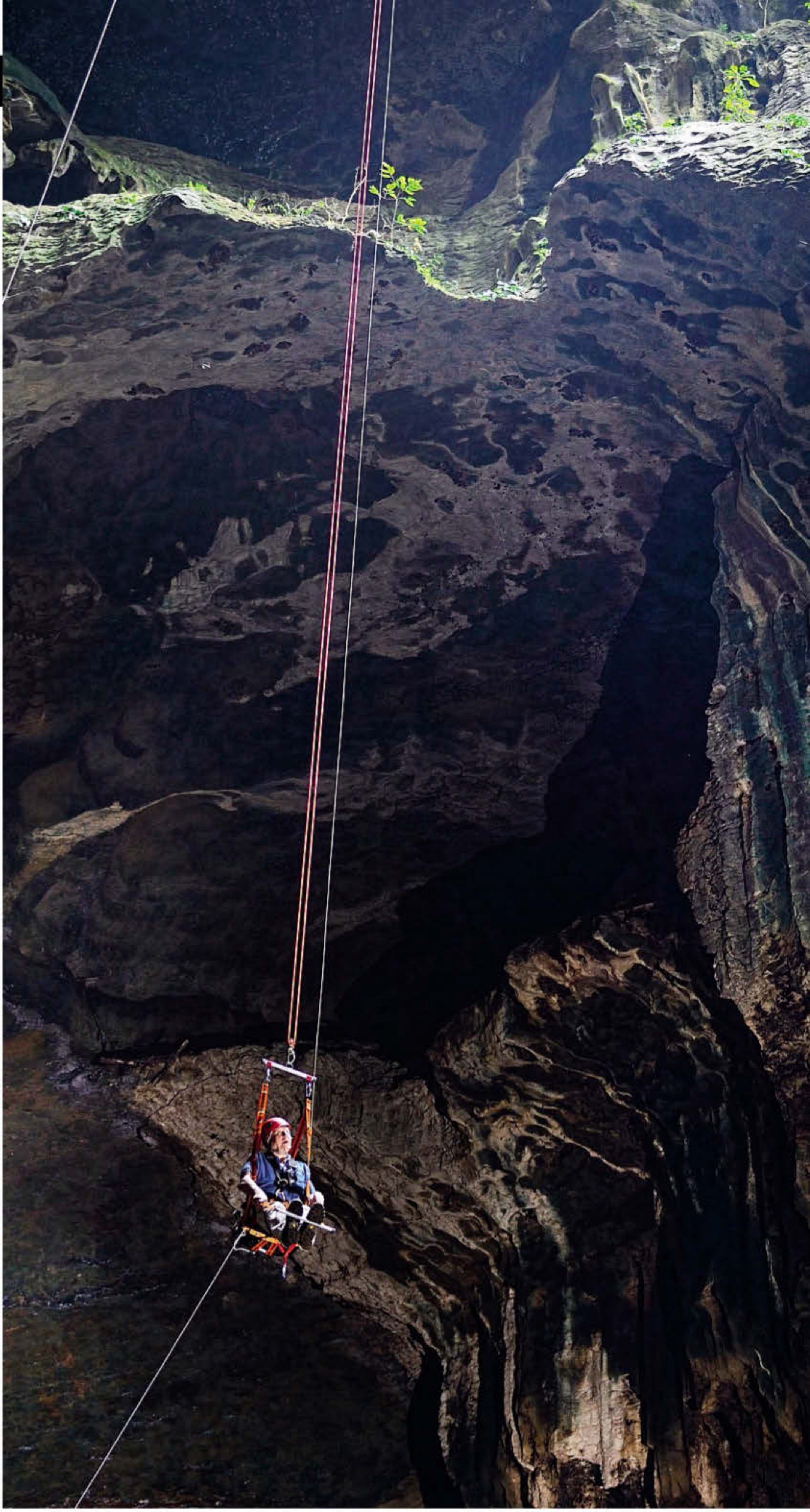
KEEPING IT REAL

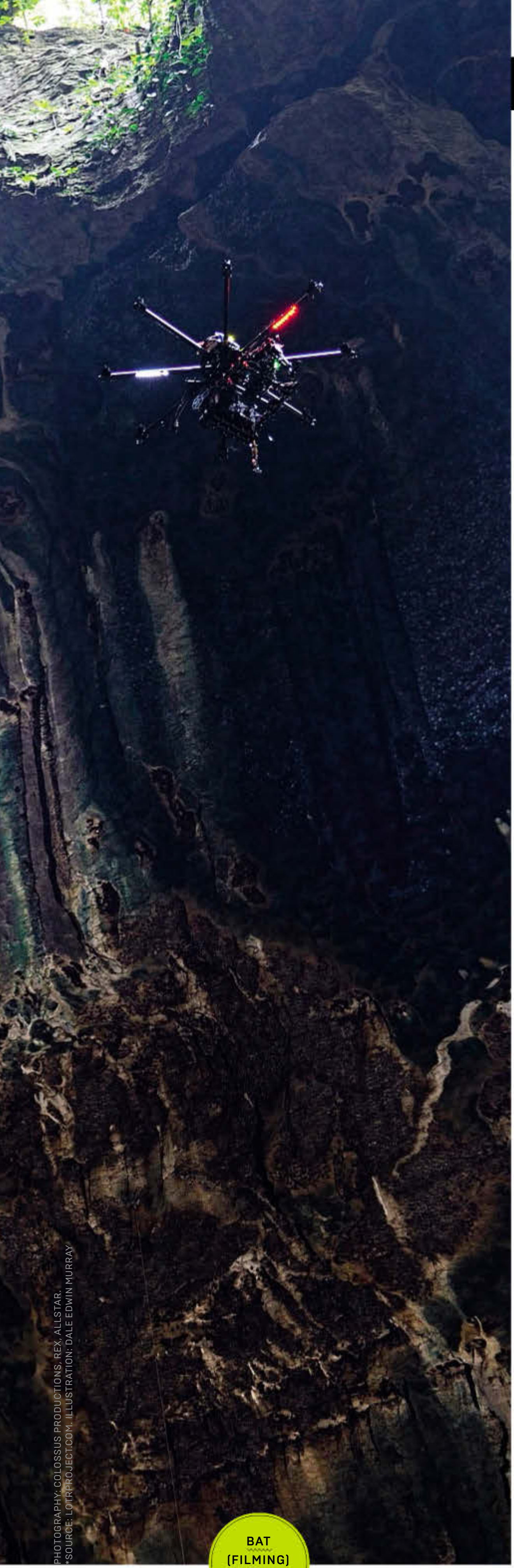
Want some *real* reality TV? Just log in to YouNow. The New York-based lifecasting site – a cross between Chatroulette and Twitch – claims it hosts 100,000 daily broadcasts. "Other live video services focus on utility," says founder Adi Sideman, 44. "We built a place to meet new people and for self-expression."

Founded in 2011 and backed by Union Square Ventures and Orens Capital, YouNow claims 100 million monthly users who watch via the site and smartphone app. New broadcasts are tagged and move up or down a queue according to votes.

Alongside thousands of YouNow users inviting people into their homes, the service is popular among budding social-media stars – in June, the musician Shawn Mendes debuted his first single, "Life of the Party", live to 35,000 fans. The broadcast trended, and the song jumped to third on the iTunes chart *during* the performance. (In October, YouNow announced YouTube-style revenue-sharing for top users.)

Other stars include Sydnie Brazile, a musician who won a music contest on YouNow in 2013, and has since been signed up to a song-writing contract. It's this quality of broadcasts that has surprised Sideman the most. "They really put their heart and soul into it," he says. **OF** *younow.com*





PHOTOGRAPHY: COLOSSUS PRODUCTIONS, REX, ALLSTAR. *SOURCE: LOTRPROJECT.COM. ILLUSTRATION: DALE EDWIN MURRAY

BAT (FILMING) MOBILE

Aerial unit

HOW DRONES HELPED DAVID ATTENBOROUGH REACH NEW HEIGHTS FOR HIS SKY 1 SERIES

Documentary film-makers have taken us from ocean trenches to snow-capped peaks; but filming animals in flight remains a challenge. "Flight is one of the most incredible things that happens on the planet," says Anthony Geffen, executive producer of 3D nature series *Conquest of the Skies*. "But how do you capture that?"

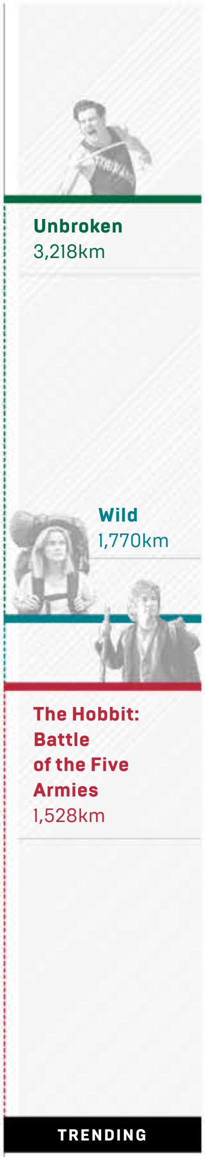
Helicopters are too loud and light aircraft are limited to flying at certain heights. The answer: drones. For the new Sky series, narrated by iconic naturalist David Attenborough, the production team used an octocopter custom-built by production company Colossus and Digital Cinema Films. Weighing 9.2kg, the drone carries two stabilised 5K Red EPIC cameras to enable ultra HD and 3D filming.

While shooting a sequence on bats nesting in the Gomantong Caves in Borneo, Attenborough found himself hoisted 100 metres up so he could present to the new camera (*left*). "[With drones] the opportunity of making something fairly spectacular exists," says Attenborough. "You have everything going: slow-mo, highly sensitive cameras, you've got the lights and you've got 3D."

Conquest of the Skies has also been filmed for Oculus Rift using an eight-camera 360° rig. "We thought, who would be cooler in virtual reality than David?" says Geffen. Their next project, *Alchemy VR*, will be a documentary about the earliest life on Earth and will use live-action 3D, HD and CGI.

"[1998's *The Life of Birds*] was good at the time," says Attenborough. "But what we're able to do now is just mind-blowing."

Chris Baraniuk Conquest of the Skies *starts in December on Sky 1 HD and Sky 3D*



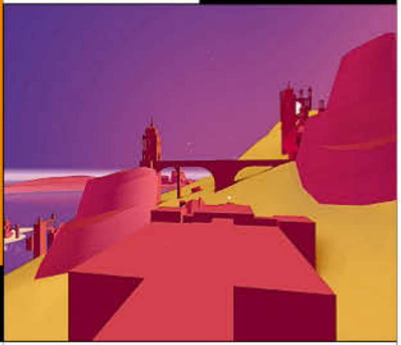
TRENDING

Epic film journeys
This month's big cinematic trend: ultra-long, gruelling treks, whether by foot or sea. Here's how some recent marches match up. **OF**

Playlist

◀ DRUM HERO
Upgrade your table-tapping: the Korg CLIPHIT can turn any hard surface into an electronic drum kit. Vibration sensors turn your inputs into a choice of sounds and an audio input allows you to play along to that thrashing solo. *£99.99 korg.com*

▲ POST-SNOWDEN FASHION TIPS
Worried you're going to get hacked? UK-based fashion brand The Affair has you covered. The UnPocket wallet shields your smartphone from Wi-Fi and 3G signals, so you're protected from prying eyes. *£18 1984.the-affair.com*



▲ VIRTUAL SURREALITY
Loved ustwo's MC Escher-like game *Monument Valley*? The UK studio's latest effort *Land's End* levels up the surreal aesthetic in a beautiful platformer made for the Samsung Gear VR headset. *ustwo.com*

◀ LIGHT SHOW
Head to London for *DOM* at Gazelli Art House. It explores digital art in the physical world, such as Aaron Koblin and Ben Tricklebank's *Light Echoes* (*left*), in which the artists "paint" on outdoor scenes using lasers. On until January 17. *gazelliarthouse.com*

▼ PAPER DRONES
PowerUp Toys 3.0 can turn a paper plane into a battery-powered, smartphone-controlled microdrone with a 55m range. There's also a bath-friendly boat version (but you should stick to waterproof paper for the latter). *$49.99 poweruptoys.com*

▲ SPACE RACE IN THE HOMEPLACE
This table is Maxim Scherbakov's tribute to *Sputnik 5*, the first Russian mission to include living creatures. A pot inside the space-age frame can be used to grow your own plants. *€700 plan-S23.com*

▶ UNIQUE VIBRATIONS
LA-based DJ Jennifer Lee – aka TOKiMONSTA – combines surreal samples, urgent beats and experimental tech (turning a sushi machine into a sampler), with stunning results. *tokimonsta.com*

PHOTOGRAPHY: ROGER STILLMAN; THEO JEMISON

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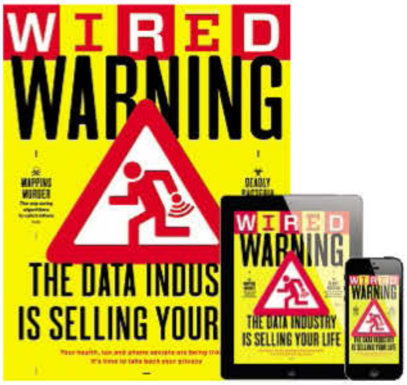
12.14 BUCKLE UP! THE WORLD'S FIRST 1,000MPH CAR



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1 2
3 4

1/Patek Philippe flagship store opening

This watch brand has been making timepieces since 1851, but it hasn't stood still. Besides new designs, such as the white gold 5270G chronograph, Patek Philippe has also extended its flagship store in London, combining 15 and 16 New Bond Street to create a 420m^2 space.
£188,940
patek.com

2/Oakley 30th anniversary special editions

To celebrate 30 years of Oakley, the brand has created an anniversary range that reinvents its classic designs. The Special Edition Heritage Eyeshades update the 1984 performance-eyewear originals with hot new colours and improved nose-pad construction.
£190
oakley.com

3/iRobot Roomba 880 cleaning robot

The latest in cleaning technology, the Roomba uses iRobot's iAdapt system to navigate its way around the messiest of homes. Set a cleaning schedule to suit you, and then sit back and watch as it uses acoustic sensors to ensure every speck of dust gets picked up.
£599.99
irobot.co.uk

4/Creed Aventus cologne

In the fragrance business since 1760, Creed has created a shelf-full of classic men's fragrances. Launched to celebrate the brand's 250th year, Aventus is a spirited scent designed for men of adventure. With notes of blackcurrant and peppery rose, it's juicy and fresh.
£175 for 75ml
creedfragrances.co.uk

WIRED INSIDER'S PICK OF UPCOMING EVENTS

ARS TECHNICA UK LAUNCH

In April 2015, the UK version of Ars Technica, the leading US digital and technology news site, will go live. Spearheaded by Nate Lanxon – also editor of wired.co.uk – it will offer in-depth analysis of science, technology policy and business news.
April 2015, arstechnica.co.uk

COGNICITY CHALLENGE

The Cognicity Challenge offers a pair of startups an intensive 12-week training programme to develop and deploy smart city technology in London's Canary Wharf. Afterward, one team will be awarded £50,000 of investment.
Applications open January 2015, cognicity.london

CLERKENWELL DESIGN WEEK

With a claim of more architects per square mile than anywhere in the UK, Clerkenwell is the perfect location to host an event celebrating designers and creators. Now in its sixth year, expect lively debates and exciting ideas.
May 19-21, 2015, clerkenwelldesignweek.com

TOBACCO DOCK

Originally built in 1812, Tobacco Dock has, during the last two years, found a new lease of life as a world-class events venue. From product launches and food fairs to the Bafta Gaming Awards – and yes, WIRED2014 – it caters to occasions large and small.
To book, see tobaccodocklondon.com

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PHOTOGRAPHY: SUN LEE

HOW TO

ILLUSTRATION: LEO ESPINOSA

How to...
Light a fire with a water bottle

Water is normally used to put out a fire, but you can actually use it to start one. Grant "The King of Random" Thompson (youtube.com/thekingofrandom), an airline pilot, came up with this technique after a flight attendant mentioned that she saw a water bottle near a window burning a hole in a piece of paper. This accidental fire source can be harnessed to produce an emergency flame (when the Sun is shining). **Jeremy Cook**

How to...

Light a fire with a water bottle

FOLD YOUR PAPER

For this experiment, you'll need a sunny day, three sheets of paper and a clear, full water bottle with a curved top. The first piece of paper is folded three times down the middle so that it can "create the solid base of embers you'll need when you start blowing it into a flame", says Thompson. This piece should have a black spot to absorb heat when the light shines on it. You can smear dirt on the paper if you don't have a black pen.

CATCH THE RAYS

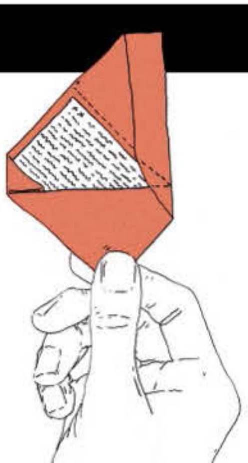
Use the curved top edge of the water bottle as a magnifying glass to concentrate light from the Sun on to the black spot. A good method is to start close and back away until the beam is focused. After that, it should take a few seconds for the paper to smoke. When the smouldering grows to about 25mm, add more layers of paper and swing them back and forth. Flames should eventually burst from the bundle.

PRACTISE FIRST

It took Thompson three months to perfect the technique, so it's good to practise with this experiment long before an emergency arises. According to Thompson, "trying to learn this in the midst of a survival situation will probably result in failure." In an emergency you can also use coloured bottles and less than clear liquid – even urine – but the clearer your tools are, the more likely your success.

How to...

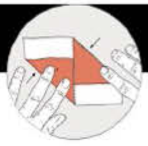
Make a bleach-patterned T-shirt



How to...

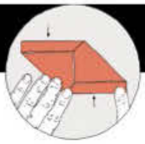
Make an origami envelope

Origami is an interesting and relatively cheap art form. Heather Shida, who's been making origami since the age of ten and now instructs others online in this art, based this gift-card envelope design on a traditional origami construction. JC



INITIAL FOLDS

Start with a 150mm x 112mm sheet of paper. Crease it in the middle then unfold it. Fold the top-right corner down the middle crease to form a triangle. Fold the opposite corner to the middle in the same fashion.



MAKE A PARALLELOGRAM

Take one of the two unfolded edges ending with a 90° corner and fold in half to meet the next folded triangle. Repeat on the opposite side. You'll have what looks like a parallelogram with an extra segment at each of the acute angles.

Bleach is used for all kinds of things, not least for cleaning and brightening dirty clothes. The disadvantage that sometimes comes into play is that too much bleach can ruin a perfectly good dark shirt by making it too light. But if you can control the bleaching process and lighten only certain parts of it, an artistic effect can be achieved. JC

WHAT YOU'LL NEED

You'll need a shirt that's a 50/50 polyester and cotton blend, bleach, water and a small spray bottle. Some use a 50/50 bleach/water mix, but undiluted bleach can also be used. To make the template, you'll need an X-ACTO knife and thin, clear plastic material (0.1mm-thick Dura-Lar works well). You'll also need tape and spray adhesive.

PREPARE THE STENCIL

Take your plastic and cut a pattern or picture using the X-ACTO knife. If the plastic is clear, an outline of a picture from a newspaper, or possibly your favourite monthly magazine, can be used as a template for your shape. Tape the plastic over your design before cutting so it doesn't slide, then trace the edges you've selected with the knife.

BLEACH IT

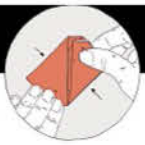
Lay the shirt flat and insert a piece of plastic behind the area that you'd like to bleach a pattern into. Spray the adhesive on to your template, then press it firmly on to the shirt. Once the template is secure, spray a mist of bleach inside it. Cover the outside of the template with more plastic, or just try not to get too much bleach outside it.

DRY IT OFF

Let your shirt air dry for around 15 minutes, then rinse it by itself to dilute everything. Dry your shirt either on a line or in the dryer, then try it on. Depending on the mixture of bleach you used and the original colour of the shirt, the bleached area will be lighter, although not necessarily white. The colour may fade more when washed.

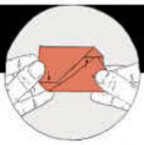
GO FURTHER

Using a thin piece of plastic is maybe the most obvious way to make a template. However, you could use any number of objects (bike gears, for example) by themselves. For a more exact template, if you have access to more "exotic" tools, one could be made with a 3D printer, laser cutter or any number of other machines.



FORM THE ENVELOPE

Starting with the corner you just folded, or the acute corner of the parallelogram, take it and fold to the middle at a 45° angle. Repeat on the opposite side. Done correctly, you should end up with a rectangle with two chamfers.

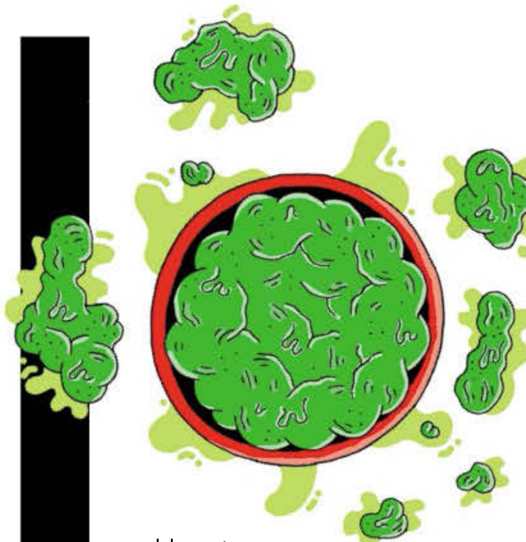


FINISH AND USE

Take the sides that you just folded and tuck them into the tabs resulting from the previous step. You'll now have something resembling an envelope. To insert a letter, remove the paper out of the tabs, insert and refold.

BEYOND
THE FOLD

ILLUSTRATION: RAJ DHUNNA; DAVID DORAN; SAM TAYLOR



How to...

Make glowing jelly

Science you can do at home is even better when you can eat the results. Here's a simple and fun method of making glowing jelly. Before you eat it, this eerie stuff can teach you about fluorescence. Robert Simpson

Ingredients

You'll need some tonic water, a packet of jelly and an ultraviolet (UV) torch or lamp. Quinine gives tonic water its taste but it is also fluorescent. It absorbs UV photons and re-emits them as visible light (UV light is higher-energy than optical light).

Chose your jelly carefully

Quinine glows a blue-ish colour so you want to use blue or green to maximise the effect. The jelly acts as a filter to the fluorescence, so using red jelly would result in only a dull glow. Lime-flavoured jelly complements tonic quite well.

Use a 1:1 mix

Make the jelly as indicated on the packet, but replace half of the water with tonic. Mix it up well and put it in the fridge. It's a good idea to pour it into glasses or transparent plastic containers to set, as it helps to maximise the glowing effect.

Set up your UV light

Place the jelly in a dark room and turn on your UV. With the UV light on, try looking at other fluorescent things around the house: highlighter pens, paper, most laundry detergent and some toothpastes all glow well.

How to...

Scrum manage

Jeff Sutherland first published his manifesto for the Scrum management framework – inspired by the rugby scrummage and prescribing small, multi-skilled teams and flexible planning – in 1995. He's since implemented it at Google, Yahoo!, Adobe and Microsoft, which incorporates it into its development process. But it's not just for software. "I've seen Scrum used successfully to build cars, run a laundry, teach students in a classroom, make rocket ships, plan a wedding... You can even – as my wife does – use it make sure that the 'honey do' list gets done every weekend," he says in his book, *Scrum* (Random House Business). Here's how to plan your life with Sutherland's system. **Kathryn Nave**

1 / SCRAP THE BUSINESS CARDS

"The first thing you want is small, cross-functional teams - having lots of narrow specialists is a huge waste of time," says Sutherland. Other than general team members, the only two roles you should establish are: the product owner, who understands your customer, has a vision for the product and decides in what order things should be done; and the ScrumMaster, who's responsible for arranging meetings, facilitating communication and removing obstacles in the team's way. Both should avoid giving orders, but guide and assist the team to achieve goals.

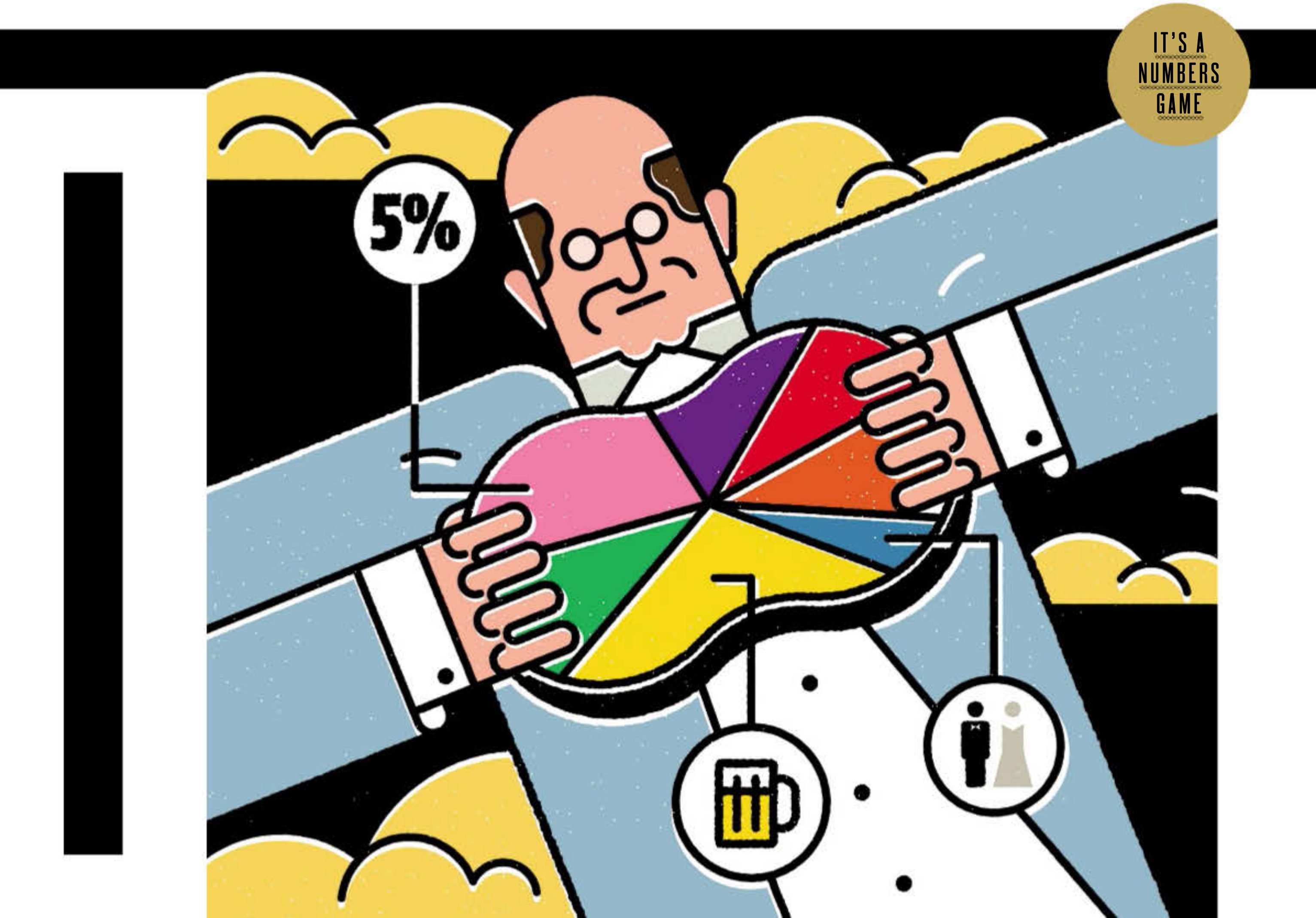
2 / DON'T SET TASKS, TELL STORIES

At every stage it's essential that team members know why they're building each individual feature, and what value it's supposed to offer the customer. This can get lost in a simple list of what needs doing. "Instead of tasks, tell stories from the point of view of the user," says Sutherland. For example. "As a customer, I want to see books organised by category, so I can find the types of books I like." Keeping this in mind while building each feature ensures that you're creating it to do exactly what your customer wants it to do.

3 / EFFORT POINT THE STORIES

Once you have a long list, called the backlog, of all the things that your customer will want to do with your product, you need to estimate the time that each will take to implement. Humans are notoriously bad at absolute estimates of time, but much more accurate at relative estimation. Instead of assigning each story a time period of days or weeks, assign it effort points relative to other stories. This allows you to order tasks by how long they'll take to achieve without making time commitments too soon.

IT'S A NUMBERS GAME



4 / PRIORITISE FEATURES

At the end of each of your iterative tasks, or sprints, your aim is to have a completed feature that can be demoed, to provide value to the customer as quickly as possible. "The product owner needs to assess which features will offer the most revenue, balanced against the effort that they will take to implement," explains Sutherland. This won't work if your stories are big, overarching goals like "build a new engine". So for any stories that have particularly high-effort point estimation, break them up into smaller, more manageable pieces.

5 / PLAN YOUR FIRST SPRINT

Now you're ready to begin your first sprint, a set period in which you decide you're going to complete a certain number of items from the top of that list. "An ideal period should be between one to four weeks," explains Sutherland. For the first sprint it's your best guess as to how many effort points you should aim to complete, but make sure the stories you select will amount to a demonstrable piece of added value by the end of the sprint. "Rolling new stuff out every few weeks means you can get constant feedback on what's working and what isn't," says Sutherland.

6 / MEET UP DAILY

One of the most important principles of Scrum is that everyone should know everything. "In the early 90s, a Bell Labs study found that effective information sharing among members meant teams worked as much as 50 times faster," says Sutherland. Every day the team should gather for 15 minutes, standing up, with the ScrumMaster asking three questions: what did you do yesterday to help the team finish the sprint? What will you do today to help the team finish the sprint? What obstacles are in the way? This way, any problems are addressed immediately.

7 / HAVE A SPRINT RETROSPECTIVE

At the end of each sprint you should have a meeting to ask broader questions about how the sprint went. The focus shouldn't be on blaming individuals, but identifying sticking points that can be eliminated for next sprint. Are your estimations of how much effort each task will take accurate? Are you focusing on developing the right features first? "The outcome of this meeting should be an improvement to the way you're working that can be implemented in the next sprint," says Sutherland. "The goal of Scrum is continuous improvement".

How to...

Massage statistics

Gary Smith, professor of economics at Pomona College in California, says computers have made it much easier to fiddle with numbers. "We don't see the eight hours spent massaging them – we just see the published result," he says. His book *Standard Deviations* (Gerald Duckworth & Co) breaks down the tricks of statistical manipulation. **KN**

FIND RANDOM CORRELATIONS

"If you look at two things that increase over time, it could be beer sales and marriages, shoe sales and births, these things will tend to be highly correlated – say a correlation of 0.9 or higher," says Smith. "It's not necessarily the case that these two things have anything to do with each other." Any two things that grow as the population increases can be correlated, but this doesn't show that increased drinking causes more marriages, or that more marriages leads to increased drinking.

CREATE A THEORY AROUND THE DATA

"This is something common to self-improvement and management books," says Smith. "You take a selection of, say, successful marriages, look at what they share, then claim these things are the key to their success. But you'll always find something in common." The right thing to do is to make a prediction as to what will be shared. Then take a selection of newlyweds, some who have these and some who don't, and look forwards to see if your prediction pans out.

PRUNE THE DATA

"This works if you already have a theory that you want to support and you find the data doesn't quite do what you need," says Smith. Researchers at the University of California were taken with the idea that Chinese and Japanese aversion to the number four might lead to higher incidences of heart attacks on the fourth of the month. The data showed no relationship, but the researchers cut out various categories of coronary death, reporting only a selection that supported their claim.

IGNORE SELF-SELECTION BIAS

"In the social sciences our experiments often involve categorising people, observing their behaviour, and then trying to draw conclusions from this," says Smith. The problem is that people aren't truly randomly assigned to these groups. For example, the reason a graduate's life turns out a certain way could be because they are the sort of person who makes the choice to go to university, rather than because of their going to university itself.

ILLUSTRATION: STEFANO MARRA; JAMIE MILLS

Let the voice of Naim take you inside the music

Mu-so is our first wireless music system. Finely tuned by our specialist engineers in England, its powerful digital brain delivers the most exceptional quality in sound, commanding 450 watts of power through six custom-designed speakers, to create an experience of music that has to be heard to be believed.

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AirPlay is a trademark of Apple Inc.

FEATURES

ARTWORK: ERIC STANDLEY, USING 108 LAYERS OF LASER-CUT ARCHIVAL PAPER. THE WORK WAS DRAWN IN CORELDRAW OVER A ONE-MONTH PERIOD AND CUT WITH A UNIVERSAL LASER SYSTEMS PLS 60-WATT CO_2 LASER, OUTFITTED WITH HIGH POWER DENSITY FOCUSING OPTICS

“No one can visualise four dimensions. Three dimensions are hard enough.” Stephen Hawking, p112

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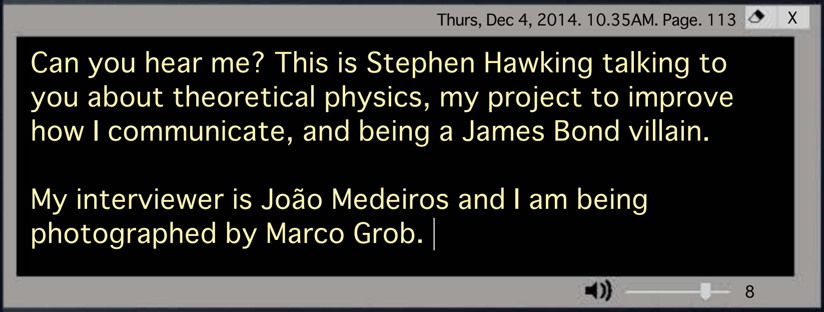
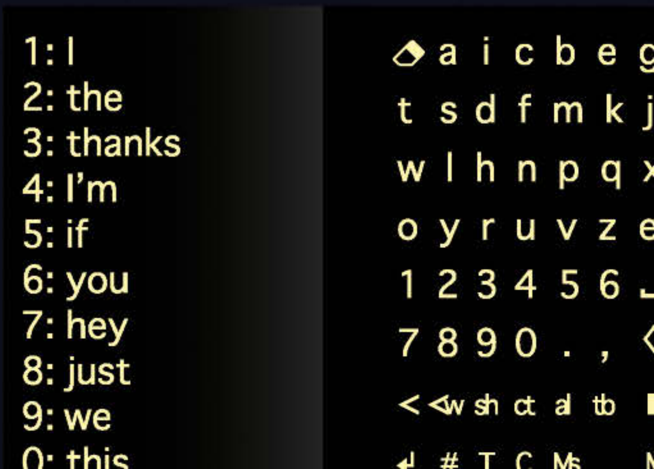


Can you hear me? This is Stephen Hawking talking to you about theoretical physics, my project to improve how I communicate, and being a James Bond villain.

My interviewer is João Medeiros and I am being photographed by Marco Grob.



PROFESSOR HAWKING IS A VERY SLOW WRITER.

FOR FIVE DECADES, HAWKING HAS USED HUMOUR AND GEOMETRIC INSIGHT TO EXPLAIN THE UNIVERSE

BY JOÃO MEDEIROS

On the afternoon of September 23, 2014, a few minutes before his lecture at the Magma auditorium in Los Pueblos in Tenerife, Stephen William Hawking was rewriting parts of his speech. Hawking, who is unusual in being both a theoretical physicist working on some of the most fundamental problems in physics (his most recent paper, in January 2014, was titled "Information preservation and weather forecasting for black holes") and being very famous, is a slow writer.

He operates his computer by moving his right cheek muscle. The movements are detected by an infrared sensor attached to his spectacles allowing him to move a cursor on a computer screen attached to his wheelchair. He painstakingly builds sentences at a rate of a few words per minute, a speed that might be slowly decreasing as his muscle control deteriorates. His condition is a consequence of amyotrophic lateral sclerosis (aka motor neurone disease), an illness from which he has suffered since the age of 21 (he took part in the ALS ice bucket challenge in August by volunteering his children: "Because I had pneumonia last year it would not be wise for me to have a bucket of cold water poured over me"). His Tenerife lecture was titled "The quantum creation of the Universe". The 1,500-capacity auditorium was packed.

"He was changing the content at the very last minute so we panicked a bit," says Jonathan Wood, Hawking's graduate assistant, a position which involves a variety of responsibilities, from technical assistance to managing social media. "He always does that. I produce the PowerPoint slides because he can't. I'm not a physicist, so often he will be talking about things that I don't understand and he'll have to explain what slides he wants." The lecture was part of the second edition of Starmus, a six-day science festival that gathered a group of eminent scientists, including physics Nobel laureate John Mather, biologist Richard Dawkins and Queen guitarist Brian May, who is an expert in three-dimensional astronomy. But the star turn was Hawking.

As he made his way to the stage, helped by his entourage of nurses and assistants, a giant screen showed a video montage which included visualisations of black-hole collisions and footage shot from Hawking's point-of-view in his wheelchair, with "Hole in the Sky", by the doom-metal band AtomA, blaring throughout the hall.

Hawking always starts his lectures with the same quip: "Can you hear me?" Hawking managed to be characteristically funny while guiding the audience through the bold ideas he has developed about the origins of the Universe over the past decades. This delivery, a blend of humour and complicated theoretical physics, is the kind of performance that Hawking, 72, is now well-known for, even as he has become a celebrity ambassador for science, a physicist whose office is adorned with portraits taken with Barack Obama, Bill Clinton and Steven Spielberg (twice) as well as stills from his many appearances in *Star Trek* and *The Simpsons*.

"I attended his famous inaugural lecture: 'Is the end in sight for theoretical physics?'" says physicist Neil Turok, a longtime friend and collaborator. "The whole lecture was given in a very amusing tone, really nothing more to it than a series of jokes. He was bold and naïve and stuck his neck out and said he thought within 20 years it would all be wrapped up. Twenty years later, he gave another lecture, titled 'Is the end of theoretical physics finally in sight?' He conceded he probably had to wait another 20 years."

Hawking's public persona manages to combine Carl Sagan's popular appeal with Richard Feynman's maverick brilliance for theoretical insight. He has deftly packaged his theories and thoughts (he is known to be able to reflect deeply about physics even when engaged in social events) in popular books, from *A Brief*

INTRODUCTION

BREAKTHROUGHS
TENERIFE
PERFORMING U-TURNS

Page.114

Tablet extra!
Download the WIRED app to read more of "The Science" (*opposite*)

IMAGE: TWENTIETH CENTURY FOX/REX. SPOT ILLUSTRATION: STUDIO MUTI

History of Time – a bestseller which almost single-handedly launched the popular-science publishing industry – to *The Grand Design*, co-written with physicist Leonard Mlodinow in 2010. These books more than anything demonstrate Hawking's propensity for concise and bold statements laced with an unconventional humour. Here, for example, is Hawking deliberating on the idea of the multiverse, the notion that the Universe doesn't have a unique history, but rather that there exists a collection of all possible histories of the Universe, all equally real and with their own set of physical laws: "There might be one history in which the Moon is made of Roquefort cheese," he writes. "But we have observed that the Moon is not made of cheese, which is bad news for mice."

Hawking's public role doesn't detract from the fact that, over the past five decades, he has been one the boldest explorers of the cosmos, at least in the realms of thought – his mind roams in theoretical dimensions that, for the most part, remain inaccessible to experiment and direct observation. Through necessity (he's no longer able to write equations), Hawking has developed an original way of thinking about the mysteries of the cosmos, not relying so much on equations as most physicists do, but preferring to think in terms of pictures and geometries. Such tools are allied to an approach that aims to make big, intuitive breakthroughs, rather than incremental contributions, in our understanding of the cosmos.

"He has pioneered completely new areas in physics," says Kip Thorne, a physicist at Caltech and one of the world's foremost experts in general relativity. "There were several key junctures in his career when he'd make a huge breakthrough and everybody else was struggling to catch up or struggling to understand."

Stephen Hawking (*below, right*), in "Anthology of Interest I", episode 16, series two of *Futurama*, in 2000

The manner in which he blazed from breakthrough to breakthrough, particularly in his most prolific period in the 70s and the 80s, was unorthodox, as Hawking not only regularly demonstrated a far-reaching insight, but also a penchant for dramatic about-turns. Here is a theoretician who first proved that the Universe starts with a singularity – an event in space and time where all the laws of physics break down – and then, with collaborator James Hartle, developed his "no boundary" proposal, which suggests that time didn't exist before the Big Bang and, therefore, the Universe doesn't have a beginning. ("It makes no sense to talk of a time before the Universe began. It would be like asking for a point south of the South Pole.")

He was also one of the first physicists to put forward a set of laws for the dynamics of black holes, including one that stated that black holes can never get smaller, but later discovered that they can indeed get smaller – in fact, they could evaporate through radiation (known today as Hawking radiation). That result was very contentious, generating a debate that lasted decades, as evidenced by the title of a book published by the physicist Leonard Susskind, *The Black Hole War: My Battle With Stephen Hawking to Make the World Safe for Quantum Mechanics*.

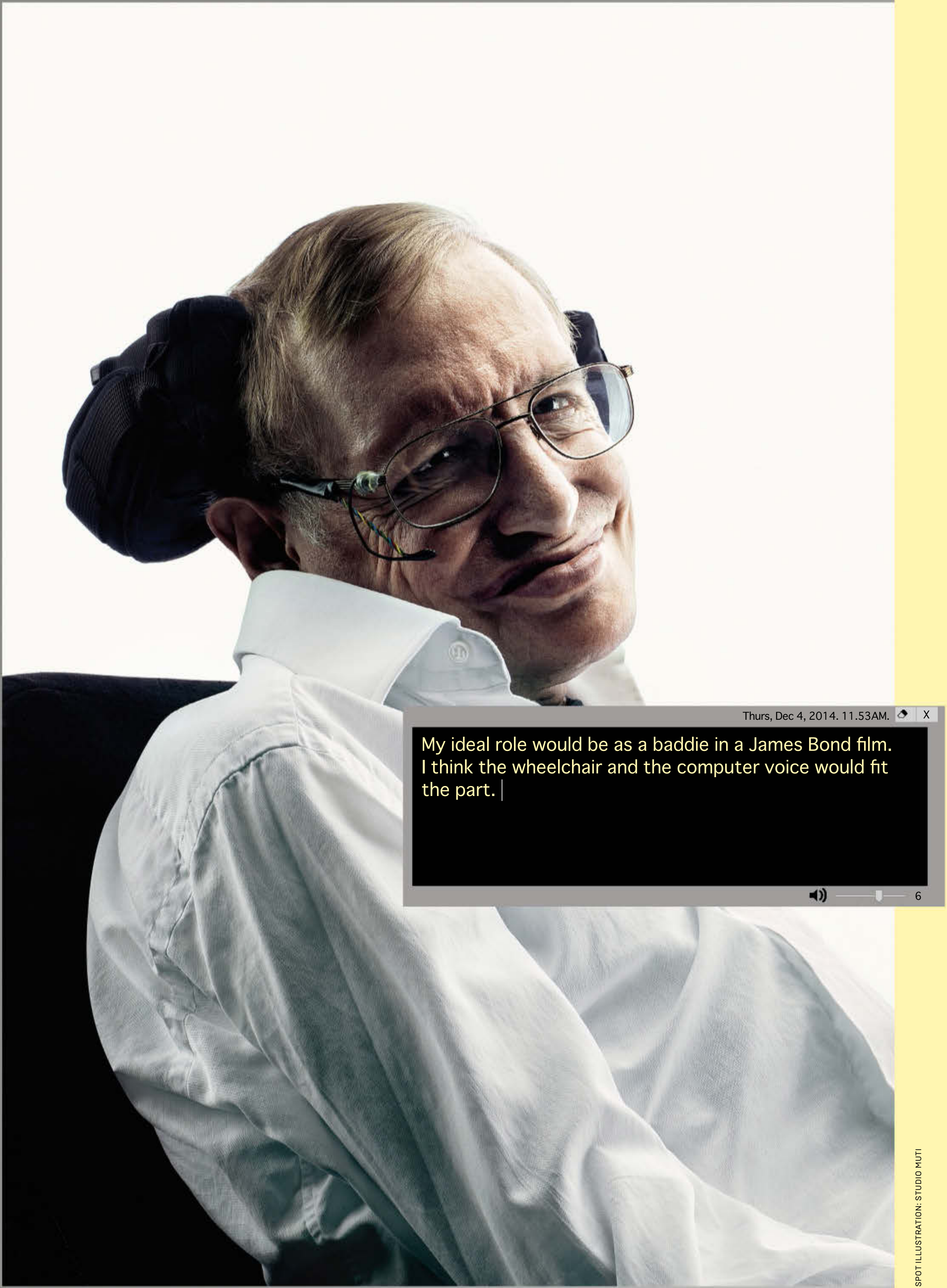
WIRED met Stephen Hawking the day after his lecture; his nurse, Patricia Dowdy, held his hand, to enable a light handshake, while Jeanna York, his personal assistant, made the introductions. His team has developed an idiosyncratic way of communicating with him, asking mostly questions that require only a yes or no answer and closely watching his facial expressions to interpret his thoughts and feelings. Hawking travelled to Tenerife by boat (his doctor forbade him from flying because of his health), a journey that took six days.

He was in good spirits, frequently flashing a smile that defies the stillness of his body. Exhaustion is probably the condition he is most familiar with, but that has never stopped him from extensive travelling, both physically and mentally. And that is what perhaps defines him the most: his unbreakable persistence. "I am just a child who has never grown up," he writes in his autobiography, *My Brief History*. "I keep asking 'how' and 'why' questions. Occasionally, I find answers."

THE SCIENCE

SINGULARITY IN OUR PAST

In 1965, while still a PhD student at Cambridge, Hawking learned about the ideas of mathematician Roger Penrose. He'd shown that once a dying star contracted to a certain radius it would be crushed to a singularity, a point where space and time came to an end. Hawking realised that the same approach could be applied to the Universe itself. "He did a simple and very ingenious thing by realising that you could use the exact result in a reverse-time direction and on a huge cosmological scale," Penrose says. Hawking predicted that the Universe had also started with a singularity.



My ideal role would be as a baddie in a James Bond film. I think the wheelchair and the computer voice would fit the part.

SPOT ILLUSTRATION: STUDIO MUTI

WIRED MEETS THE PROFESSOR

IN AN INTERVIEW WITH WIRED'S SCIENCE EDITOR, STEPHEN HAWKING DISCUSSES EUREKA MOMENTS, HIS CURRENT RESEARCH AND, OF COURSE, BLACK HOLES

BY JOÃO MEDEIROS

WIRED: What lessons in cosmology do you think the WIRED reader needs to understand if they are to keep up with current thinking?

Stephen Hawking: They need to understand that the Universe began with a period of inflation in which it expanded at an ever-increasing rate. Quantum fluctuations would have caused some regions to have expanded slower than the rest of the Universe. These regions would eventually stop expanding and collapse to form galaxies, stars and all the structure in the Universe. Quantum fluctuations during inflation would also generate primordial gravitational waves.

[The mathematician] Roger Penrose has mentioned that you always ask awkward questions. What questions are you asking right now?

I'm working on how to reconcile the apparent loss of information when a black hole evaporates with our understanding of physics that information is never lost. I raised the question 40 years ago and, despite a large number of papers since, no satisfactory resolution of the paradox has been proposed. Indeed, it has been shown that there is a contradiction between information not being lost and the usual assumption that physics is local. It has been suggested that the resolution is that there is a firewall just outside a black hole that would burn up anything falling in, but I don't believe in firewalls. Instead I think space-time is warped.

You also believe that the Universe doesn't have a single past but various possible histories. What kind of experimental evidence would be needed to prove this theory?

Feynman's idea of a sum over histories is that a system evolves by every path of history. This can be demonstrated by directing a stream of particles at a sheet with two slits in it. The number of particles arriving at a subsequent screen will form fringes, as if they were light rays. The interpretation is that each particle has two alternative histories, one going through one slit, and the other through the other slit, and they interfere like light rays.

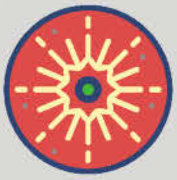
In your book *The Grand Design*, you write that M-theory is the theory that Einstein was hoping to find, one that predicts and describes the Universe, and that physicists were led to it by abstract considerations of logic. However, the theory hasn't been confirmed by observations. If experimental physics weren't limited by current technology and financial budgets, what predictions from your theories would you love to confirm empirically? And if you could devise an experiment without such constraints, what would that experiment be?

I'm beginning to have doubts about M-theory, but there seems no viable alternative. M-theory presumes supersymmetry is a symmetry between matter particles, like the electron, with force-carrying particles, like the photon. Supersymmetry would imply that all the particles we know have superpartners, but none have been found. The experiment I would like performed is to detect Hawking radiation from a black hole, because then I would win the Nobel Prize. >

THE SCIENCE

BLACK-HOLE EXPLOSIONS

In 1973, Hawking first attempted to combine general relativity (the theory of the very large) with quantum theory (the theory of the very small) by considering how quantum particles would behave near a black hole. This resulted in one of his most famous predictions: black holes radiate thermal radiation, by which they consequently got smaller until exploding. The prediction of such radiation – since then termed Hawking radiation – overturned black-hole theories. Hawking doubted his own calculations but he presented his results at a scientific meeting in 1983. The moderator stood up and said, "Sorry, Stephen, but this is absolute rubbish."



Q&A

WARPED SPACE-TIME
HAWKING RADIATION
HOW TO WIN THE NOBEL

Tablet extra!
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Hawking radiation is very difficult to detect, because the radiation from a black hole with mass a few times that of the Sun would have a temperature of only a millionth of a degree above absolute zero. Smaller primordial black holes would have a higher temperature but there don't seem to be any around.

Your longtime friend, physicist Kip Thorne, has described how, as you lost the use of your hands, you developed a powerful set of tools that no one else has, including an unusual ability to manipulate mental images of objects, curves, surfaces, shapes, not merely in three dimensions but in the four dimensions of space and time. Can you describe that mental process? Do you think you managed to solve problems that others couldn't because of that special set of mental tools?
No one can visualise four dimensions. Three dimensions are hard enough. What I do is visualise two-dimensional sections, remembering they are part of a four-dimensional whole. This geometric visualisation I used in proving singularity theorems and my work on black holes, including black-hole radiation. My disability makes it difficult to write down complicated equations so I prefer problems with a geometric interpretation.

You said that there's nothing like the eureka moment of discovering something new. Can you describe your favourite eureka moment?
I was getting into bed shortly after the birth of my daughter, Lucy. My disability made this slow, so I had time to think about black holes. Suddenly I realised that if two black holes collided and merged, the area of the horizon of the final black hole would be greater than the sum of the areas of the original black holes. I was so excited I didn't get my sleep that night.

There was a point in your life where you lost the ability to speak and, in effect, to communicate. Later, you wrote *A Brief History of Time*, which reshaped the science publishing landscape and opened up the market for popular-science books. Where does your desire to communicate science come from?
I was able to speak with a speech synthesiser, though it gave me an American accent. I have kept that voice, because it's now my trademark. Before I lost my voice, it was slurred, so only those close to me could understand, but with the computer voice, I found I could give popular lectures. I enjoy communicating science. It is important that the public understands basic science, if they are not to leave vital decisions to others.

You have long defended the view that we should colonise other worlds. How would humanity achieve this?
I believe that the human race will not survive indefinitely on Earth without some disaster. I would like us therefore to spread out into space, so humanity doesn't have all its eggs in one basket, or on one planet.

Can you tell us more about the work you're developing with Intel to develop technology that would improve the speed at which you can communicate, such as text-prediction engines, brain interfaces, facial recognition and other sensors?
Intel has created a writing program for me using predictive text which allows me to write faster. The program is activated by a small sensor on my glasses. I'm writing these answers using it. Intel is going to open source it, to make it available to other disabled people. Intel has also tried facial recognition, though the range of messages that can be conveyed is limited. I have not had much success with brain-computer interfaces. My carers say it's because I have no brainwaves.

You've been on *The Simpsons*, you took part in a documentary directed by Errol Morris and produced by Steven Spielberg, and acted on *Star Trek*. What would be your ideal movie role? Also, what are your views on current pop culture?
My ideal role would be a baddie in a James Bond film. I think the wheelchair and the computer voice would fit the part. I know little of popular culture, having spent my time on science.

Q&A

EUREKA MOMENTS
SPEECH SYNTHESIS
JAMES BOND VILLAINS

Page.118

Tablet extra!
Download the WIRED app to read the full Morris and Penrose interviews

ERROL MORRIS ON HAWKING

Film-maker and director, Stephen Hawking's *A Brief History of Time*

On what drew him to making the film:
"The book has been misdescribed. It's not a primer on theoretical physics: it's a biography. Hawking was talking about himself as he wrote about black holes as regions of space-time cut off from the rest of the Universe, from which nothing can escape. It was hard not to relate that to his physical condition."

On Hawking's sense of humour:
"We recreated a facsimile of his Cambridge office and so there were all these photos of Marilyn Monroe. I remember one fell off the wall during filming and Hawking typed, 'A fallen woman'. He's been to our home in Cambridge, Massachusetts, many times – he used to call it the "pseudo-Cambridge". One of my favourite anecdotes is asking, 'Of course, you can't see into a black hole, but if you could what would you see?' He clicks away and after a long while says: 'Seven leather-bound volumes of Proust.'"

KIP THORNE

Professor of theoretical physics, Caltech

How Hawking changed the way he thought about scientific problems:
"As he lost the use of his hands, and could no longer write equations, he developed, far better than anyone else has in history, an ability to use geometrical and topological images in his head to solve problems. That enabled him to see things that other people didn't see. It was central to a lot of his discoveries."

On Hawking's personality:
"He knows that he's smarter than almost all the rest of us. He has both the courage and the enthusiasm to work in an area regardless of who else and how many other people are working in it. He has the ability to make huge breakthroughs in highly popular areas. I can only make a huge breakthrough if nobody else is working in that area."

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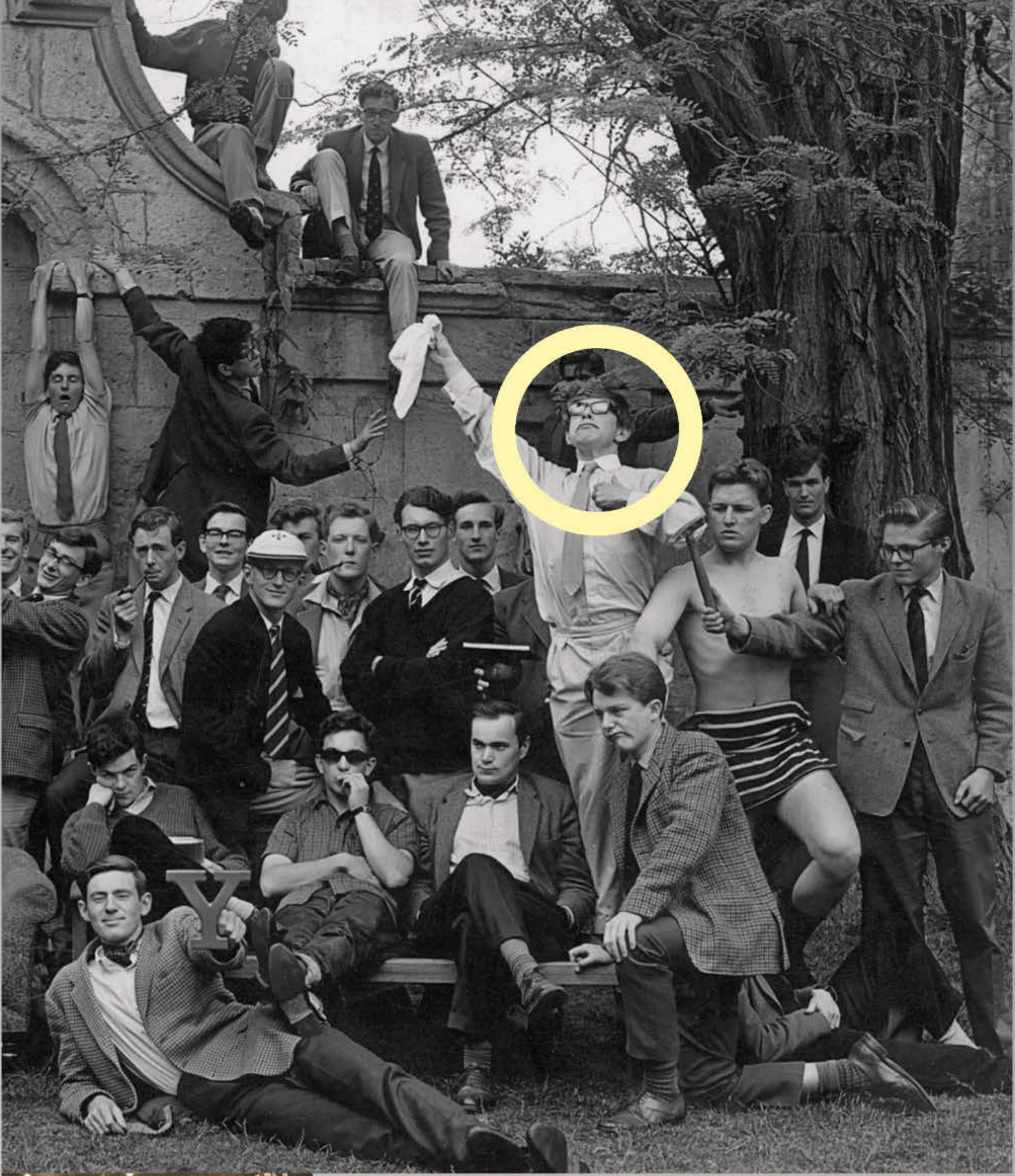

HAWKING ON SCREEN

Main picture: Hawking and the other members of University College Boat Club, for whom he coxed. **Far left:** Felicity Jones as Jane Wilde, who would be Hawking's first wife, and Eddie Redmayne as Hawking in the recent biopic *The Theory of Everything* (2014) **Bottom left:** Hawking playing poker with Einstein, Newton and Data in *Star Trek* ("Descent", the 1993 series six finale). **Left:** one of Hawking's four appearances in *The Simpsons* ("They Saved Lisa's Brain", the 22nd episode of the tenth series, which first aired in 1999)

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Stephen Hawking
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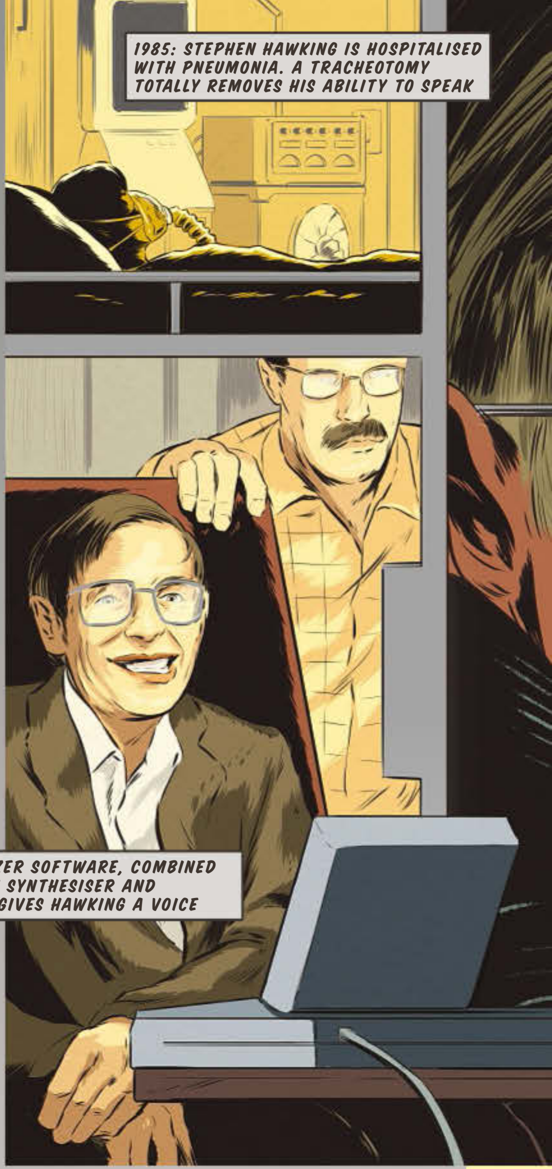
GIVING HAWKING A VOICE

WHEN HAWKING LOST HIS VOICE, HE SOUGHT A DIFFERENT SCIENTIFIC BREAKTHROUGH

BY JOÃO MEDEIROS
ILLUSTRATION: GUY SHIELD



1985: STEPHEN HAWKING IS HOSPITALISED WITH PNEUMONIA. A TRACHEOTOMY TOTALLY REMOVES HIS ABILITY TO SPEAK

1986: EQUALIZER SOFTWARE, COMBINED WITH A VOICE SYNTHESISER AND AN APPLE II, GIVES HAWKING A VOICE

Stephen Hawking first met Gordon Moore, the cofounder of Intel, at a conference in 1997. Moore noticed that Hawking's computer, which he used to communicate, had an AMD processor and asked him if he preferred instead a "real computer" with an Intel microprocessor. Intel has been providing Hawking with customised PCs and technical support since then, replacing his computer every two years.

Hawking lost his ability to speak in 1985, when, on a trip to CERN in Geneva, he caught pneumonia. In the hospital, he was put on a ventilator. His condition was critical. The doctors asked Hawking's then-wife, Jane, whether they should turn off the life support. She vehemently refused. Hawking was flown to Addenbrooke's Hospital, in Cambridge, where the doctors managed to contain the infection. To help him breathe, they also performed a tracheotomy, which involved cutting a hole in his neck and placing a tube into his windpipe. As a result, Hawking irreversibly lost the ability to speak.

For a while, Hawking communicated using a spelling card, patiently indicating letters and forming words with a lift of his eyebrows. Martin King, a physicist who had been working with Hawking on a new communication system, contacted a California-based company called Words Plus, whose computer program Equalizer allowed the user to select words and commands on a computer using a hand clicker. King spoke to the CEO of Words Plus, Walter Woltosz, and asked if the software could help a physics professor in England with ALS. Woltosz had created an earlier version of Equalizer to help his mother-in-law, who also suffered from ALS and had lost her ability to speak and write. "I asked if it was Stephen Hawking, but he couldn't give me a name without permission," says Woltosz. "He called me the next day and confirmed it. I said I would donate whatever was needed."

Equalizer first ran on an Apple II computer linked to a speech synthesiser made by a company called Speech Plus. This system was then adapted by David Mason, the engineer husband of one of Hawking's nurses, to a portable system that could be mounted on one of the arms of a wheelchair. With this new system, Hawking was able to communicate at a rate of 15 words per minute.

However, the nerve that allowed him to move his thumbs kept degrading. By 2008, Hawking's hand was too weak to use the clicker. His graduate assistant at the time then devised a switching device called the "cheek switch". Attached to his glasses, it could detect, via a low

SYNTHESIS

LOSING SPEECH
CHEEK SWITCH
COMPLICATIONS

Page.122

Tablet extra!
Download the WIRED app to see more examples of Hawking's big ideas

SPOT ILLUSTRATION: STUDIO MUTI

2008: NERVE DEGENERATION MEANS HAWKING MUST NOW COMMUNICATE USING A CHEEK-SWITCH CONTROLLER
2013: WITH INTEL ENGINEERS, HAWKING'S ASSISTANT INSTALLS A NEW ITERATION OF HIS TEXT-TO-SPEECH INTERFACE
2014: HAWKING EXPERIMENTS WITH CONTROLLING HIS ELECTRIC WHEELCHAIR VIA A CHIN-JOYSTICK

Previous spread: Hawking experiences a zero-weight moment during a flight on a Zero Gravity jet above Orlando, Florida, with ZG's cofounder Peter Diamandis, on April 26, 2007. **Near left:** Jonathan Wood and Hawking

infrared beam, when Hawking tensed his cheek muscle. Since then, Hawking has achieved the feat of writing emails, browsing the internet, writing books and speaking using only one muscle. Nevertheless, his ability to communicate continued to decline. By 2011, he managed only about one or two words per minute, so he sent a letter to Moore, saying: "My speech input is very, very slow these days. Is there any way Intel could help?"

Moore asked Justin Rattner, then Intel's CTO, to look into the problem. Rattner assembled a team of experts on human-computer interaction from Intel Labs, which he brought over to Cambridge for Hawking's 70th birthday conference, "The state of the Universe", on January 8, 2012. "I brought a group of specialists with me from Intel Labs," Rattner told the audience. "We're going to be looking carefully at applying some state-of-the-art computing technology to improve Stephen's communicating speed. We hope that this team has a breakthrough and identifies a technique that allows him to communicate at levels he had a few years ago."

Hawking had been too ill to attend his own birthday party, so he met the Intel experts some weeks later at his office in the department of applied mathematics and theoretical physics at the University of Cambridge. The team of five included Horst Haussecker, the director of the Experience Technology Lab, Lama Nachman, the director of the Anticipatory Computing Lab and project head, and Pete Denman, an interaction designer. "Stephen has always been inspirational to me," says Denman, who also uses a wheelchair. "After I broke my neck and became paralysed, my mother gave me a copy of *A Brief History of Time*, which had just come out. She told me that people in wheelchairs can still do amazing things. Looking back, I realise how prophetic that was."

After the Intel team introduced themselves, Haussecker took the lead, explaining why they were there and what their plans were. Haussecker continued speaking for 20 minutes, when, suddenly, Hawking spoke. "He welcomed us and expressed how happy he was that we were there," says Denman. "Unbeknown to us, he had been typing all that time. It took him 20 minutes to write a salutation of about 30 words. It stopped us all in our tracks. It was poignant. We now realised that this was going to be a much bigger problem than we thought."

At the time, Hawking's computer interface was a program called EZ Keys, an upgrade from the previous softwares and also designed by Words Plus. It provided him with a keyboard on the screen and a basic word-prediction algorithm. A cursor automatically scanned across the keyboard by row or by column and he could select a character by moving his cheek to stop the cursor. EZ Keys also allowed Hawking to control the mouse in Windows and operate other applications in his computer. He surfed the web with Firefox and wrote his lectures using Notepad. He also had a webcam that he used with Skype.

The Intel team envisaged an upheaval of Hawking's archaic system, which would involve introducing >

THE SCIENCE

INFORMATION LOSS

Hawking radiation seems to violate a fundamental principle of quantum mechanics – the notion that information is preserved in nature; it is devoid of any information about the black hole that emitted it. In 1997, Hawking and Kip Thorne had made a bet with physicist John Preskill. Hawking and Thorne believed that information was swallowed by black holes, whereas Preskill believed the problem would be solved by a more complete theory of physics. "The loser will reward the winner with an encyclopaedia of the winner's choice, from which information can be recovered at will," said Hawking and Thorne in a joint statement. In 2004, Hawking conceded: "It is like burning an encyclopedia: the information contained in the encyclopedia is not technically lost if one keeps all the smoke and ashes, but it is very hard to read."

new hardware. "Justin was thinking that we could use technology such as facial-gesture recognition, gaze tracking and brain-computer interfaces," says Nachman. "Initially we fed him a lot of these wild ideas and tried a lot of off-the-shelf technologies." Those attempts, more often than not, failed. Gaze tracking couldn't lock on to Hawking's gaze, because of the drooping of his eyelids. Before the Intel project, Hawking had tested EEG caps that could read his brainwaves and potentially transmit commands to his computer. Somehow, they couldn't get a strong enough brain signal. "We would flash letters on the screen and it would try to select the right letter just by registering the brain's response," says Wood. "It worked fine with me, then Stephen tried it and it didn't work well. They weren't able to get a strong enough signal-to-noise."

"The more we observed him and listened to his concerns, the more it dawned on us that what he was really asking, in addition to improving how fast he could communicate, was for new features that would let him interact better with his computer," says Nachman. After returning to Intel Labs and after months of research, Denman prepared a ten-minute video to send to Hawking, delineating which new user-interface prototypes they wanted to implement and soliciting his feedback. "We came up with changes we felt would not drastically change how he used his system, but would still have a large impact," says Denman. The changes included additions such as a "back button", which Hawking could use not only to delete characters but to navigate a step back in his user interface; a predictive-word algorithm; and next-word navigation, which would let him choose words one after another rather than typing them.

The main change, in Denman's view, was a prototype that tackled the biggest problem that Hawking had with his user interface: missed key-hits. "Stephen would often hit the wrong key by hitting the letter adjacent to the one he wanted," says Denman. "He would miss the letter, go back, miss the letter again, go back. It was unbearably slow and he would get frustrated." That particular problem was compounded by Hawking's perfectionism. "It's really important for him to have his thoughts articulated in exactly the right way and for the punctuation to be absolutely right," says Nachman. "He learned to be patient enough to still be able to be a perfectionist. He's not somebody who just wants to get the gist of the message across. He's somebody who really wants it to be perfect."

To address the missed key-hits, the Intel team added a prototype that would interpret Hawking's intentions, rather than his actual input, using an algorithm similar to that used in word processing and mobile phones. "This is a tough interaction to put your faith into," the video explained. "When the iPhone first entered the market, people complained about predictive text but quickly distrust turned to delight. The problem is that it takes a little time to get used to and you have to release control to let the system do the work. The addition of this feature could increase your speed and let you concentrate on content."

The video concluded: "What's your level of excitement or apprehension?"

In June that year, Hawking visited Intel Labs, where Denman and his team introduced him to the new system, initially called ASTER (for ASsistive Text EditoR). "Your current piece of software is a little dated," Denman told him. "Well, it's very dated, but you're very used to using it, so we've changed the method by which your next-word prediction works and it can pretty much pick up the correct word every single time, even if you're letters away from it."

"This is a big improvement over the previous version," Hawking replied. "I really like it."

They implemented the new user interface on Hawking's computer. Denman thought they were on the right path. By September, they began to get feedback: Hawking wasn't adapting to the new system. It was too complicated. Prototypes such as the back button, and the one addressing "missed key-hits", proved confusing and had to be scrapped. "He's one of the brightest guys in the world but we can't forget that he hasn't been exposed to modern technology," says Denman. "He never had the opportunity to use an iPhone. We were trying to teach the world's most famous and smartest 72-year-old grandfather to learn this new way of interacting with technology."

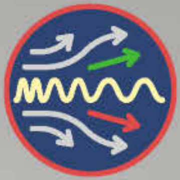
Denman and the rest of the team realised that they had to start thinking differently about the problem. "We thought we were designing software in the traditional sense, where you throw out a huge net and try to catch as many fish as you can," says Denman. "We didn't realise how much the design would hinge on Stephen. We had to point a laser to study one individual."

At the end of 2012, the Intel team set up a system that recorded how Hawking interacted with his computer. They recorded tens of hours of video that encompassed a range of different situations: Stephen typing, Stephen typing when tired, Stephen using the mouse, Stephen trying to get a window at just the right size. "I watched the footage over and over," says Denman.

THE SCIENCE

INFLATION

In 1982, Hawking renewed his interest in the early Universe, after a new theory suggested it had gone through a period of inflationary expansion. He showed that in such a Universe, minute irregularities arising from thermal fluctuations would later give rise to galaxies and planets, a result independently corroborated by others. Those fluctuations were later confirmed experimentally by the COBE satellite in 1992. Inflation further predicts the existence of gravitational waves and an experimental team in the South Pole, BICEP2, claimed in March 2014 to have observed them. But results from COBE's successor satellite experiment, Planck, are incompatible with such results. The two teams are currently working together to reach an agreement on the data analysis.



ICONS FIT FOR AN ICON

In order to make communication easier, Intel designed a set of shortcut icons for Hawking's computer system:

- ❤ Switch application
- ✂ Cut
- 🗐 Copy
- ✎ Erase everything in the talk window
- 💾 Save
- ⌂ Home page
- 📁 History folder
- ❤ Switch between open docs

SYNTHESIS

TOO MUCH MODERNITY
INAPPROPRIATE SPEECH
LOST FLOPPY DISCS

Page.124

Tablet extra!
Download the WIRED app to read more profiles of Stephen Hawking

PHOTOGRAPHY: ANDREW B MYERS. SPOT ILLUSTRATION: STUDIO MUTI

"Sometimes, I would run it at four times the speed and still find something new."

By September 2013, now with the assistance of Jonathan Wood, Hawking's graduate assistant, they implemented another iteration of the user interface in Hawking's computer. "I thought we had it, I thought we were done," says Denman. However, by the following month, it became clear that, again, Hawking was having trouble adapting. "One of his assistants called it 'ASTER' torture," recalls Denman. "When they said it, Stephen would grin."

It was many more months before the Intel team came up with a version that pleased Hawking. For instance, Hawking now uses an adaptive word predictor from London startup SwiftKey which allows him to select a word after typing a letter, whereas Hawking's previous system required him to navigate to the bottom of his user interface and select a word from a list. "His word-prediction system was very old," says Nachman. "The new system is much faster and efficient, but we had to train Stephen to use it. In the beginning he was complaining about it, and only later I realised why: he already knew which words his previous systems would predict. He was used to predicting his own word predictor." Intel worked with SwiftKey, incorporating many of Hawking's documents into the system, so that, in some cases, he no longer needs to type a character before the predictor guesses the word based on context. "The phrase 'the black hole' doesn't require any typing," says Nachman. "Selecting 'the' automatically predicts 'black'. Selecting 'black' automatically predicts 'hole'."

The new version of Hawking's user interface (now called ACAT, after Assistive Contextually Aware Toolkit) includes contextual menus that provide Hawking with various shortcuts to speak, search or email; and a new lecture manager, which gives him control over the timing of his delivery during talks. It also has a mute button, a curious feature that allows Hawking to turn off his speech synthesiser. "Because he operates his switch with his cheek, if he's eating or travelling, he creates random output," says Wood. "But there are times when he does like to come up with random speech. He does it all the time and sometimes it's totally inappropriate. I remember once he randomly typed 'x x x x', which, via his speech synthesiser, sounded like 'sex sex sex sex'."

Wood's office is next to Hawking's. It's more of a workshop than a study. One wall is heaped with electronic hardware and experimental prototypes. Mounted on the desk is a camera, part of an ongoing project with Intel. "The idea is to have a camera pointed at Stephen's face to pick up not just his cheek movements but other facial movements," says Wood. "He could move his jaw sideways, up and down, and drive a mouse and even potentially drive his wheelchair. These are cool ideas but they won't be coming to completion any time soon."

Another experimental project, suggested by the manufacturers of Hawking's wheelchair earlier this year, is a joystick that attaches to Hawking's chin and allows him to navigate his wheelchair independently. "It's something that Stephen is very keen on," says Wood. "The issue was the contact between Stephen's chin and the joystick. Because he doesn't have neck movement it is difficult to engage and disengage the joystick." Wood shows WIRED a video of a recent test trial of this system. In it, you can see Hawking driving his wheelchair across an empty room, in fits and starts. "As you can see, he managed to drive it," says Wood. "Well, sort of."

NEIL TUROK ON HAWKING

Director of the Perimeter Institute for Theoretical Physics in Waterloo, Canada

On collaborating with Hawking:
"I write formulae on a blackboard and explain ideas. He has an unbelievable sense for when something is right or wrong. If it's right he will raise his eyebrows. If I write something he doesn't like, he squashes his face and his jaw moves sideways. He is pained. Then you realise you've got to do better, you want to see the raised eyebrows."

On Hawking's motivation:
"Stephen is obsessed with this idea that we can understand the beginning of the Universe. I think that's what keeps him alive. What we do as theoretical physicists is so hard. It makes everything else seem easy. He chose to think about the hardest problems because it takes his mind off all the other problems he has. If you make progress in fundamental physics it's an unbelievable feeling. You get a glimpse into the heart of nature. Einstein had that, Dirac as well. It gives purpose to your existence. It's an obsession that doesn't hurt anyone else and, in time, if you unravel these mysteries, it can prove incredibly fruitful for society."

Wood showed WIRED a little grey box, which contained the only copy of Hawking's speech synthesiser. It's a CallText 5010, a model given to Hawking in 1988 when he visited the company that manufactured it, Speech Plus. The card inside the synthesiser contains a processor that turns text into speech, a device that was also used for automated telephone answering systems in the 80s.

"I'm trying to make a software version of Stephen's voice so that we don't have to rely on these old hardware cards," says Wood. To do that, he had to track down the original Speech Plus team. In 1990, Speech Plus was sold to Centigram Communications. Centigram was acquired by Lernout and Hauspie Speech Products, which was acquired by ScanSoft in 2001. ScanSoft was bought by Nuance Communications, a multinational with 35 offices and 1,200 employees. Wood contacted it. "They had software with Stephen's voice from 1986," says Wood. "It looks like we may have found it on a backup tape at Nuance." Hawking is very attached to his voice: in 1988, when Speech Plus gave him the new synthesiser, the voice was different so he asked them to replace it with the original. His voice had been created in the early 80s by MIT engineer Dennis Klatt, a pioneer of text-to-speech algorithms. He invented the DECtalk, one of the first devices to translate text into speech. He initially made three voices, from recordings of his wife, daughter and himself. The female's voice was called "Beautiful Betty", the child's "Kit the Kid", and the male voice, based on his own, "Perfect Paul". "Perfect Paul" is Hawking's voice.

João Medeiros is WIRED*'s science editor. He wrote about geoprofiling in 11.14*

YOUR
AUTON

Will the inexorable logic of artificial intelligence render us obsolete, or will our fuzzy fallibility – our humanness – save us?

By **Luke Dormehl**

Illustration: **DKNG**

ARLIER THIS YEAR, DEEP KNOWLEDGE VENTURES, a Hong Kong investment house, announced that it had appointed an algorithm to its board of directors. Given the same powers as the human board members, the piece of software weighs up financial and business decisions to assess investments in biotechnology and regenerative medicine that could be worth millions of dollars. The algorithm's strength, its creators claim, is its ability to automate the kind of due diligence and historical knowledge about trends that would be difficult for a mere person to spot.

Because CEOs and senior executives routinely command seven- and eight-figure salaries based on their experience and ability, the appointment seems like a stunt concocted by a marketing department: surely no computer can make decisions superior to those of MBA-schooled executives? In fact, the really surprising thing about the Deep Knowledge Ventures algorithm isn't that it's an outlier, but how typical it is.

No matter what line of work you're in, your skills are being undermined by rapidly improving algorithms.

LESSON #1

Don't take it personally. Large-scale shifts in patterns of employment have been occurring since the days of the Industrial Revolution. Entire sectors have risen and fallen before – and they will again. Survival requires an openness to new opportunities and an awareness of emerging new fields.

EDUCATION

OUR APPROACH TO LEARNING NEEDS A RADICAL RETHINK

Your employability will increasingly depend on your repeated ability to develop new skills. The education system is not meeting these needs.

Schools and universities are based on a paradigm rooted in the Industrial Revolution, the so-called "factory model" of schooling, in which standardised lesson plans teach students specific skills for prescribed roles in the workplace.

Much of this thinking no longer applies. The factory model for schools imagined that these skills could be used by learners for the rest of their lives. Today, technological change means that many skills will be obsolete within a decade. New categories of job are constantly being invented. Why should memorisation of facts matter in the age of Wikipedia?

"Education is built around the idea that we should teach our children to store large amounts of information," says Carl Benedikt Frey, a James Martin Fellow at the Oxford Martin Programme on the Impacts of Future Technology. "Why? Instead of rote learning, we should be pushing social interactions and getting kids to solve problems in creative ways."

"There are two competing ideologies of education," says David Hursh, author of *Twenty-First Century Schools* and associate professor of education at the Warner Graduate School of Education at the University of Rochester, New York. "The first of these focuses on so-called objective assessments, standardised teaching, increased efficiency, reducing costs and ensuring that students are constantly learning and doing nothing frivolous. The second – which I'm a believer in – talks about using education to create a democratic citizenry. This means few standardised tests, if any, building more directly on teacher-student knowledge, and supporting human development. Rather than using education to train people for the workplace, it imagines that everywhere, including the workplace, should be an educational institution."

In a world of massive open online courses, high-quality education can take place anywhere. This opens up new technology-aided opportunities for people previously denied the chance of such learning. Within the next 20 years it is likely that everyone in the world will be able to learn using online courses. This will require a change in how we think about educational establishments.

"There is a real lock on certification held by a lot of more traditional establishments," says economist Tyler Cowen. "We think about Oxford and Harvard, but saying that you learned something online has nowhere near the same cachet. That really needs to evolve." **LD**

Are you a doctor? Say hello to the medical apps that can provide diagnostic information more accurately than a human health worker. A lawyer? LegalZoom and Wevorce are legal services that carry out the kind of complex tasks previously performed by a legal professional, for just a fraction of the fees. Do you work in manufacturing? 3D printers can now do much of the physical construction work previously carried out by assembly workers, and genetic algorithms (which mimic natural selection inside a computer) are now widely active in carry-out design work.

In most sectors, machines are faster, cheaper and do a more reliably consistent job than humans. They don't take sick days or holidays, don't exhibit irrational bias or leave for a better job. As artificial-intelligence systems have become more advanced, they have been disrupting more fields – and they're showing no signs of slowing down. According to a 2013 study by the University of Oxford, around 47 per cent of employment is at risk of being automated within two decades.

This isn't a contemporary phenomenon: throughout history, technological progress has constantly shifted the market's demand for skills. The invention of the internal-combustion engine, for instance, prompted a shift from an agrarian to an industrial economy and created the city as we know it. New technologies have destroyed jobs, but they've also created them. This is what economists call the "capitalisation effect", by which companies enter areas where demand and productivity are high. This is then enough to offset the destructive effects of these types of economic shifts.

What is different now is that the number of jobs being created appears lower than the number being destroyed. In the early 20th century, factory work created more than enough jobs to offset those lost in agriculture. That is not so obvious in a world where a company such as Instagram, which employed 13 people in April 2012 when it was acquired by Facebook for $1 billion (£600 million), can displace photography giant Kodak, which employed more than 140,000 at its height. Writing in 1933, the economist John Maynard Keynes noted that widespread technological unemployment is the result of "our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour".

Today it's no longer only jobs perceived as low-skill that are being disrupted: white-collar professions involving a high level of training are just as likely to be displaced by software as assembly workers in a factory. Some of this is because once-untouchable fields such as law and medicine include specialisms that are vulnerable to automation: medical diagnosis, the drafting of contracts and comparison of trademarks can be better carried out by a computer than by human beings. "What we saw happening with physical labour during the industrial revolution we're now seeing happening with cognitive labour," says Michael Osborne, associate professor in machine learning at the University of Oxford. "It's all about taking cognitive tasks and breaking them down into their smallest possible subcomponents."

Surviving this transition will be tough. It has led to – and will tend to increase – a growing polarisation between rich and poor, as a few "superstars" flourish at the top of the food chain, while median income falls at the middle market. Between 1990 and 2005, the ratio of CEO pay compared to that of the average worker increased from 70 times to 300 times.

LESSON #2

Jobs are shifting form. The old-fashioned nine-to-five with a month's paid holiday will be less common. However, new patterns of employment will offer opportunities for more flexible approaches across varying industries.

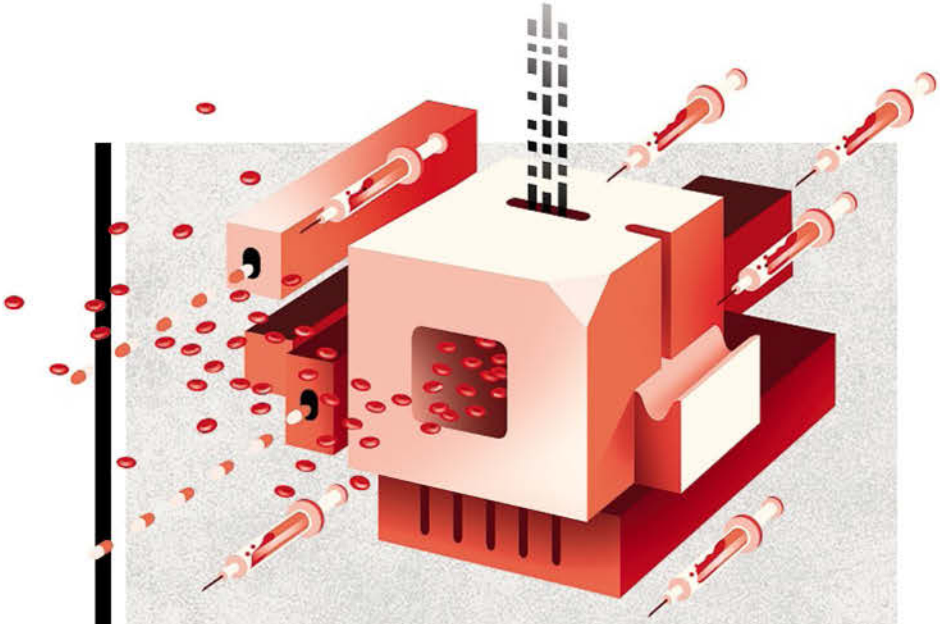


ILLUSTRATION: BORJA BONAQUE

CASE STUDY

#01

HEALTH: IBM WATSON GROUP

More than 70,000 new scientific-journal articles are published each year; the body of medical literature doubles in size every five. To keep up to date, a researcher or clinician would need to do 160 hours' worth of reading every week – then somehow find time to actually see a few patients and conduct their own trials.

"The data sources are so vast and they're exploding every day – far beyond the ability of any individual's comprehension," says IBM Watson Group VP and head of Watson Healthcare, Rob Merkel. "Yet the value of insights contained among all that could be lifesaving."

Created by IBM's DeepQA team, and made famous by its winning appearance on the US game show *Jeopardy!*, the Watson supercomputer can read and process the information in all of those journals, then present the relevant insights as a simple visualisation in response to a broad question posed by a medical professional - such as which drugs have been observed to interact with certain proteins.

At Baylor College of Medicine in Houston, Texas, it has been used to run through 24 million medical articles to discover P53 proteins, known as the "cancer-killing proteins" for their effect on tumour proliferation. "The average rate of a discovery across the entire industry has been one per year," Merkel says. "Within just a few weeks of using Watson, Baylor College alone identified six." **Kathryn Nave**

In the UK some CEOs take home more in three days than lower-paid employees make in an entire year. Although technology isn't the only reason for this, it does play a significant role. For example, it offers new income streams and potential audiences for the rock stars at the top, while removing the jobs of those underneath. The digital age enables JK Rowling to become a billionaire author by giving her more ways to monetise Harry Potter, but it also means that second-bests will find it tougher to compete.

In his book *Average is Over*, the economist Tyler Cowen writes: "One day soon, we'll look back and see that we have produced two nations – a fantastically successful nation working in a technologically dynamic sector, and everything else." But speaking to WIRED, Cowen is also optimistic. "These proportions are not fixed," he says. "I think we can get a lot more people into the rich sector. A lot depends on what kind of education and other opportunities are available to them."

This is where technology's disruptive reach can help, whether it's a MOOC (massive open online course) that offers a university-level education for free, or the connectivity that lets a UK entrepreneur set up a production line in China. Technology might be shrinking certain industries, in terms of the numbers of workers they need in order to function, but it's also making all manner of new things possible. "Automation is definitely having a big impact on certain classes of lawyer, but I don't think it's going to do away with them completely," says John Kelly, CEO and founder of Blackstone Discovery, an e-discovery firm that uses software to sort through pre-trial documents, a job that would previously have been done by junior lawyers. "For example, in the area of legal discovery, one of the big revolutions of the digital age is that there's so much more data to comb through. Whereas in the past it might have been a few boxes of paper, today we're talking about emails, texts, documents, voicemails, social-media posts, hard-drive contents. This isn't a case of algorithms shutting down fields; they're opening them up. That presents a huge opportunity for new lawyers with the right skill sets."

LESSON #3

Embrace a new role. Although some white-collar jobs will be threatened, many of the skills necessary to do them will be transferable into the new fields of employment that will emerge as the digital age reshapes the social landscape.

CASE STUDY

#02

MEDIA: NARRATIVE SCIENCE

Most journalists aim to reach an audience of at least several thousand people. With its automated article-writing software, Quill, Chicago-based company Narrative Science wants to create stories that fewer than ten people will ever read. "Quill can analyse a large data set to spot trends and perform comparisons, then identify which elements are important, build these into a narrative and express it in natural language," explains cofounder and chief scientist, Kris Hammond. "The whole process is completely automated." So, instead of using the data to provide one broad-ranging story for thousands of readers, the software can rapidly write thousands of stories tailored to each person. "It's providing a service that no human being, no organisation of human beings would ever want, or even be able to create," Hammond says. "It's less that journalists are going to be replaced, and more journalism is expanding." This might mean post-match reports for four million youth football matches or stories describing the educational performance of each one of the UK's more than 24,000 schools. "Any one piece is only going to be read by a few people," Hammond says, "but for them it's impactful, and the overall effect of all these stories is incredibly powerful." **KN**

NEW MODELS

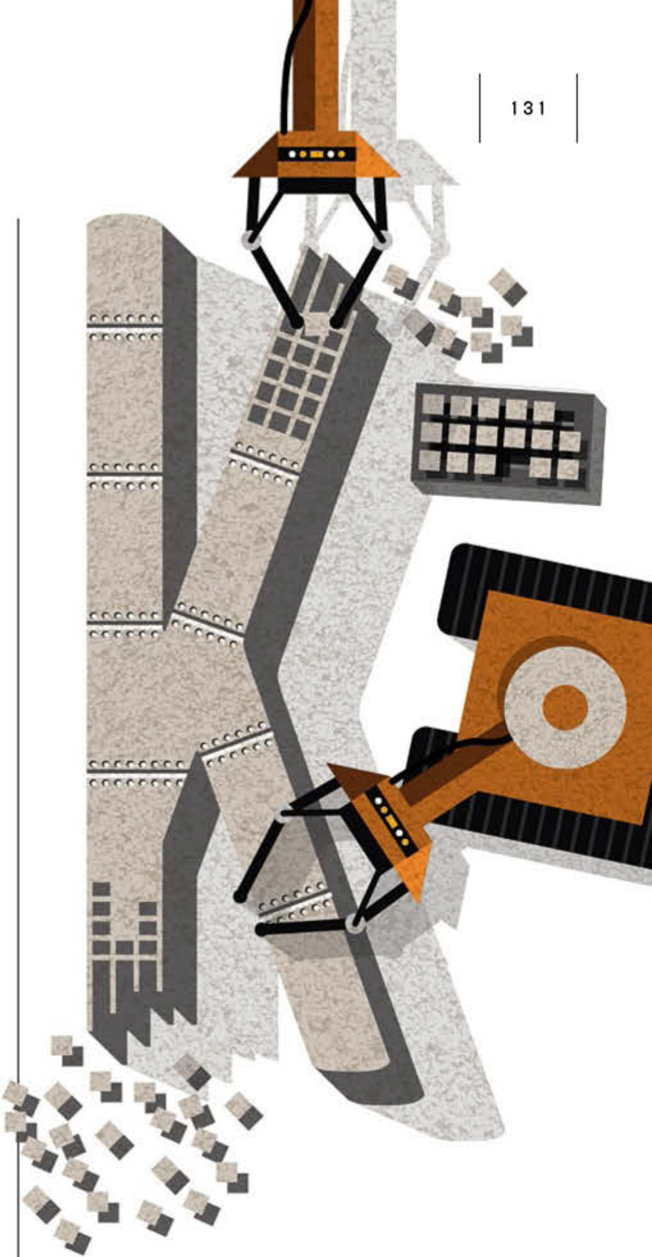
WE SHOULDN'T BE GIVING AWAY DATA FOR FREE; WE SHOULD SELL IT

It is unlikely that WIRED readers would work for free, even if their boss occasionally let them use her personal gym or swimming pool as a perk. So why don't we behave in the same way when it comes to our data? Instead of one or two companies getting rich from the data generated via digital touchpoints, everyone should gain from the new streams of revenue.

Ironically, today's data-driven artificial-intelligence systems make humans more valuable than ever. Today's AI doesn't rely on rules coded by a few programmers, but on vast data sets of collective human intelligence, which are used to make algorithms smarter. On Google Translate every word deciphered draws on the knowledge of millions of anonymous translators. Their reward is the use of online services, such as search engines, for free. As white-collar jobs move online, though, should services and their users develop a different relationship? "Data is the new oil," argued mathematician Clive Humby in 2006, who, with his wife, Edwina Dunn, sold their company, which created the Tesco Clubcard, to Tesco for £93 million. But if data really is 21st-century oil, then should users be giving away such a valuable resource in exchange for free online spreadsheets and pictures of cats? Steve Jobs showed us through iTunes that people can be persuaded to pay for music online, rather than downloading it for free. As public awareness of the power of data grows, the same thing could happen with cognitive capital.

In his book *Who Owns the Future?* virtual-reality pioneer Jaron Lanier suggests that it would be relatively simple for companies to calculate a micropayment every time a person's action helps a machine to make an intelligent decision. When Amazon sells a book based on your preferences, say, or an online dating service uses your data to provide better matches, you would receive a micropayment.

Tyler Cowen has a variation on this idea. "Machines are going to displace more jobs, but we'll be able to produce more for free," Cowen says. "It's not unthinkable that a multi-billionaire could adopt a country and give its people the technologies they need for free. They would have phenomenal healthcare and education. You can already see the beginnings of this online." The concept of a neo-feudal Google-owned nation in which citizens access services in exchange for personal data may seem dystopian, but these are the questions we should be asking as the age of automation advances. **LD**



LESSON #4

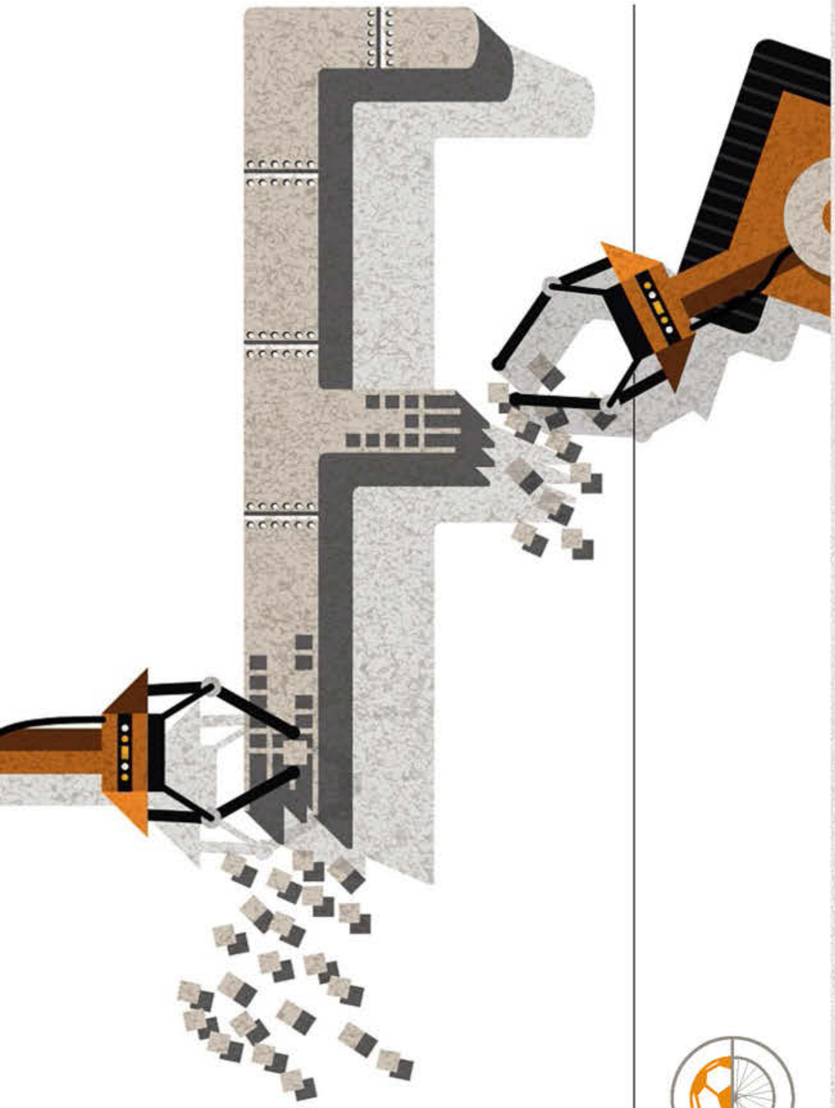
Don't panic. Although machines and algorithms will take over certain duties in areas such as law, accountancy and healthcare, automation will boost demand for emotional intelligence and human warmth as consumers seek interaction with real people, particularly in personal matters that require a sensitive approach.

EEPING ABREAST OF THESE REQUIRED SKILLS WILL be key to surviving the transition. On a personal level, people need to make sure they have the kinds of skills that computers are unlikely to be able to be a substitute for, particularly working with this technology in new and creative ways," says Erik Brynjolfsson, director of the MIT Center for Digital Business, and author of *The Second Machine Age*.

What will distinguish the jobs that are likely to last is that they will be complementary to, rather than replaceable by, machines. We need to establish which tasks machines can do better than people and vice versa. This isn't easy. In 2004, in *The New Division of Labor,* MIT and Harvard economists Frank Levy and Richard Murnane argued that computers were adept at jobs that require the following of rules, but were far less effective at dealing with pattern-recognition tasks involving unstructured data. An algorithm couldn't, they argued, drive a car because of the stream of unstructured data the vehicle would need to handle. With autonomous cars being tested on British roads from January 2015, the algorithms' progress is only going to accelerate.

JOBS VS. EMPLOYMENT

QUALITIES, NOT QUALIFICATIONS, WILL BE THE NEW CURRENCY



OR THE NEXT FEW YEARS, HUMANS WILL CONTINUE TO BE employed in areas where machines are not yet cheap or skilled enough to replace them. Logistics companies such as Amazon, for instance, are still reliant on human employees to pick and package orders. At some point in the near future, however, the staff will be replaced: the online retailer's purchase of robotics company Kiva Systems was an early step in increasing efficiency and lowering costs via a non-automated warehouse.

These advances in computation will change the tasks required of humans, but our input will not be mothballed quite yet – just adapted. In order to be safe from the destructive effects of new technologies we must recast the way we think about employment (and by extension education), picking areas in which machines will probably never be able to match humans. The industrial revolution was all about turning man into machines: simplifying complex tasks to the point where they could easily be tailored to mass-production. The digital age, by comparison, needs to adapt the new possibilities of computation to, ironically, be more human.

There's a difference between job security and employment security. The days of a single job for life may be gone, but that's not the same as employability.

Computer scientists can move from creating an algorithm to analysing star formations to working on nanotechnology; in a similar way those wanting to thrive can adapt their skills to fit a rapidly changing work environment.

One way this will play out is a move away from a model of specific job training and towards a focus on attributes. In the age of the algorithm, skills such as creativity and empathy will be prized far more highly than rote knowledge of one particular area that may be disrupted.

Several startups are already exploring this area. Israeli entrepreneur Guy Halfteck's company Knack creates mobile games that isolate and grade qualities such as quick thinking, perceptiveness and spontaneity in a way that will make them less subjective and more quantifiable for employers, giving them greater importance.

"The kinds of jobs we're going to see continued growth in are the ones that are heavily reliant on social and creative intelligence," says Carl Benedikt Frey, a James Martin Fellow at the Oxford Martin Programme on the Impacts of Future Technology. Partnering with Michael Osborne, associate professor in machine learning at the University of Oxford, Frey has tried to identify what he calls "bottleneck" – the areas in which machines find it difficult to match humans. "We've found three main ones," Frey says. "Personal intelligence, creativity and fine manipulation, which machines still cannot do well. You've got to find the jobs which require these skills. Jobs which require a high level of creative and social skill are quite difficult to automate. As a result there is a low risk that they will be subject to computerisation."

"Traits such as creativity and emotional intelligence are going to be increasingly prized," says Erik Brynjolfsson, director of the MIT Center for Digital Business. "For now, these are areas where humans have a relative edge compared with machines." Medicine is an example of a profession that will probably reflect this change. As algorithms are used for more and more diagnostic work – meaning that doctors no longer need to be repositories for *The Physicians' Desk Reference* – their role as empathic caregivers will increase. **LD**

LESSON #5

Consider retraining for one of these jobs. According to "The Future of Employment", a recent report by Carl Benedikt Frey and Michael Osborne, these roles are (for the next two decades at least) automation-proof...

Recreational therapist

Dentist

Athletic trainer

Clergy

Chemical engineer

Lawrence Katz, professor of economics at Harvard University, talks about an "artisan economy" of jobs that emphasise the bespoke, human element of work. As we become accustomed to an age of smart sensors, algorithmic selection and real-time feedback, we will also come to re-evaluate the importance of qualities such as empathy, creativity and, well, humanness.

We're already starting to see evidence of this. For instance, recently there has been a rise in the number of companies exploring human curation. One example of this is Beats Music, the company purchased by Apple for $3 billion (£1.8 billion) in May 2014. Beats stands out from some of its rivals by creating playlists that are the result of human editors, instead of machines. In August, former Apple executive Jean-Louis Gassée wrote an open letter to Apple CEO Tim Cook, suggesting that he apply the same idea to the App Store; using editorial picks over the currently employed recommender system model. Similarly, the nutrition app *Rise* matches users with human coaches rather than employing an algorithm.

Another example is *OOLOO*, a Siri-style assistant created by the storage service iDrive. Rather than focus on breakthroughs in natural-language processing, *OOLOO*'s creators believe that they have optimised their service by using humans over algorithms.

"Life is getting more and more automated, and what we've seen is a real desire on the part of users for a human connection," says iDrive CEO and president Raghu Kulkarni of OOLOO. "There's a warmth to our service, which sets us aside from some of the algorithmic options out there. There might be a bit of humour in your interaction, for example. I certainly don't think human interfaces are the only option, but we're definitely seeing more and more popularity regarding that way of thinking."

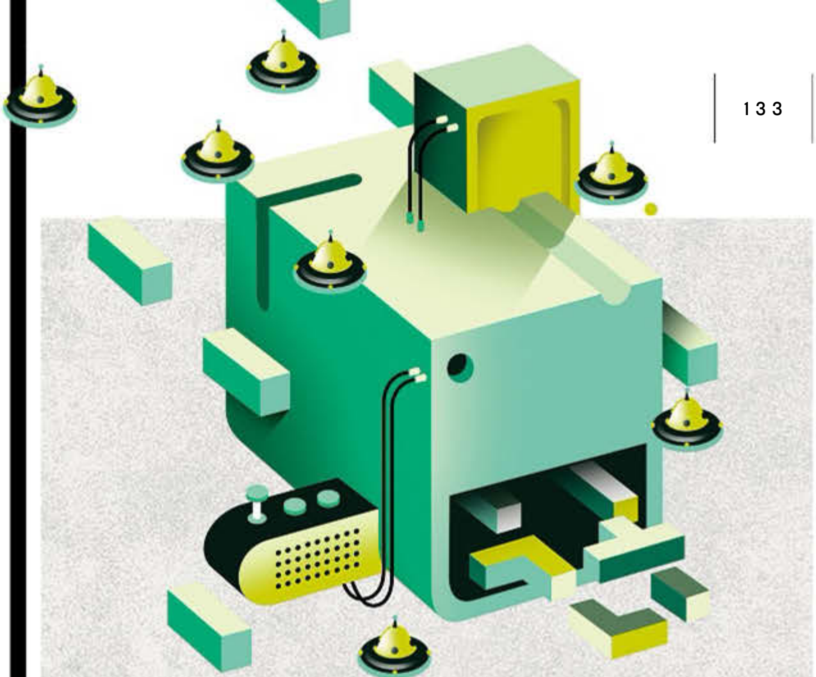
Although automation can replace people in many roles, there may be jobs that we simply don't want to hand over to machines: not because they can't do a good approximation of it, but because the result of doing so feels a little too mechanised. Algorithms, for example, can analyse the music of bands such as the Beatles, and may very soon be able to generate whole new tracks in that style without the need to pay expensive musicians. But the idea of replacing musicians, radio hosts or novelists with algorithms is one that human beings are likely to sense as peculiar.

Where to draw the line dividing computer-operated efficiency and emotionally intelligent response remains to be seen. Is that seemingly bespoke job you're interested in one where the human component is essential – or is it one where efficiency is the more highly valued and the human element could be replaced by an algorithm?

Viv Labs, a startup by several of the creators of Siri, is currently working on a virtual assistant able to deal with complex sentences like: "Get me a ticket for the cheapest flight from SFO to Charles de Gaulle on July 2, with a return flight the following Monday" or, "On the way to my brother's house, I need to pick up some cheap wine that goes well with lasagne." At present, these sentiments can be better dealt with by a person with a deep understanding of language and semantics, which is OOLOO's business model. But judging by the progress made by Viv Labs, the same won't necessarily be true a few years down the line. It depends on how much we prize qualities like humour and human spontaneity in our interactions.

"There's no single technological inevitability about the future when it comes to how it will affect employment and incomes," says Brynjolfsson. "There have been some disappointing trends when it comes to inequality and employment, but there have also been some great, positive trends, in terms of increased abundance and the overall pie getting bigger. Going forwards, we need to view technology as a tool – not an autonomous force that imposes its will on us. We shape our own destiny."

Luke Dormehl wrote about tech bubbles in 06.14



CASE STUDY

#03

GAME DESIGN: MICHAEL COOK

Procedural generation - the use of an algorithm to create infinite variations on certain elements of a game - may be the next big thing, but Goldsmith's University of London research associate Michael Cook is way ahead: his artificial-intelligence programme, Angelina, can create a game all by itself.

"Angelina works by breaking up the act of game design into lots of different tasks, like designing levels, choosing visuals and music," he explains. It can even write a mini synopsis explaining the meaning behind its choices. This is all done by the process of computational evolution, randomly generating thousands of designs, selecting those it judges as best and randomly breeding their code together in thousands of different ways, then repeatedly remixing these again.

"As with real-world evolution it should eventually produce better output, but all this randomness can get very messy," Cook says. "There's stuff that is just completely surreal, like occasionally you'll walk round a corner in one of it's games and bump into a gigantic ocean liner." So Angelina won't be putting games studios out of business any time soon, but there's the potential for it to suggest how to make their games better. "It's been able to find features in the game engine I didn't even know were possible," Cook says. **KN**

LESSON #6

If you're in one of these jobs, you need to rethink: "The Future of Employment" report claims they're ripe for automation in the next 20 years...

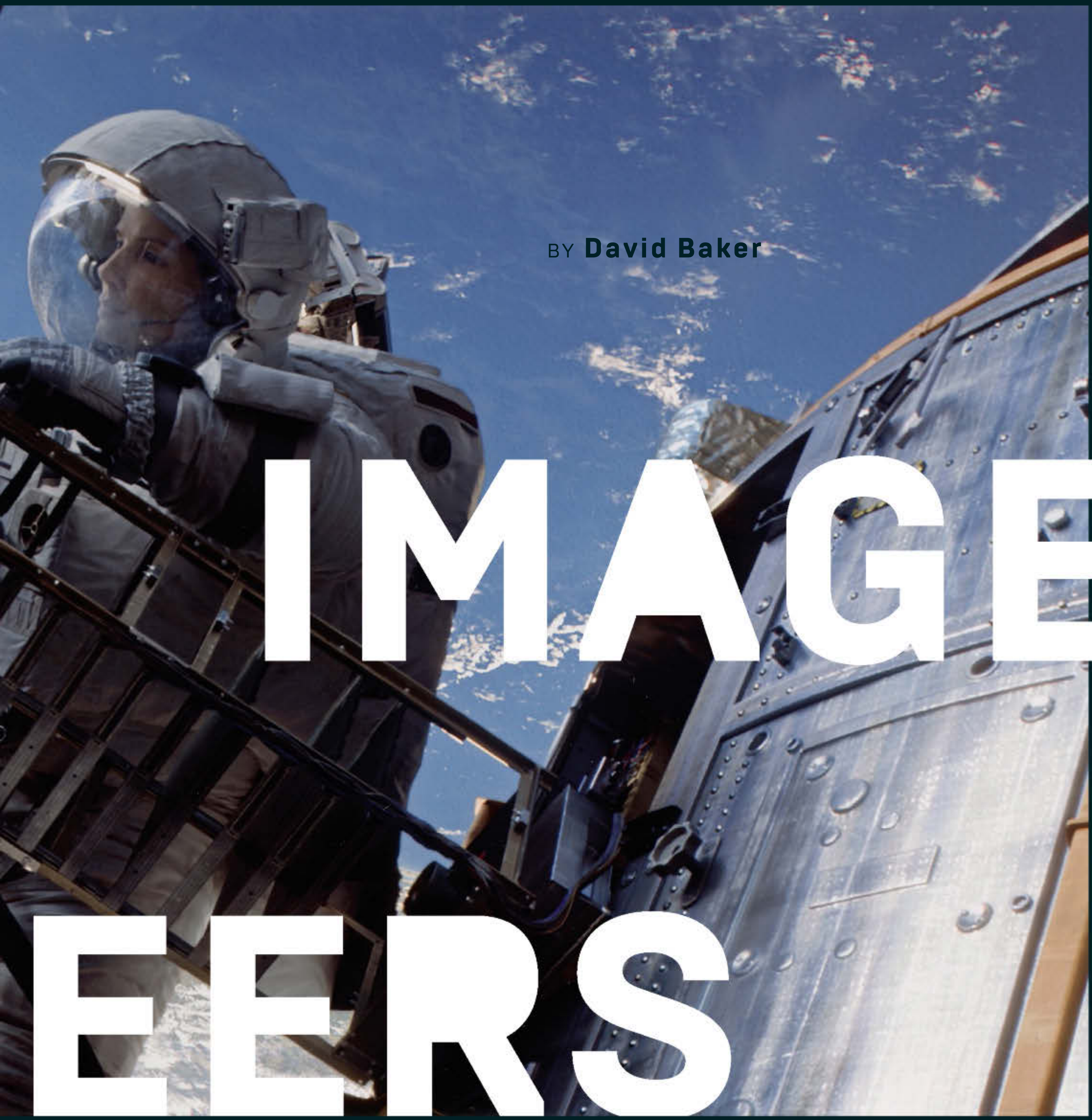
Telemarketer
Accountant or auditor
Retail salesperson
Technical writer
Estate agent

THE ENGIN

From resurrecting long-dead actors to creating an Oculus Rift tour of Westeros, London-based visual-effects experts Framestore has spent more than 25 years reworking reality

IMAGE
EERS

BY **David Baker**



IN A screening room in London's Soho, William Bartlett watches as a *Roman Holiday*-era Audrey Hepburn™ (Framestore is legally required by Hepburn's estate to add a ™ after each use of her name) steps out of a bus on the Italian Riviera, flirts her way to a free ride in an open-topped saloon and breaks into a bar of Galaxy chocolate. *Roman Holiday* was released in 1953, Galaxy was first sold in 1960 and Hepburn died in 1993. But the ad, made in 2013, brings her back to life.

Until 2014, few people outside advertising and film-making had heard of special-effects firm Framestore (Bartlett, 45, is its creative director). Based in central London, with offices in Montreal, New York and Los Angeles, it has, for most of its 28-year existence, operated behind the scenes, providing computer-generated special effects for commercials, movies and TV. At best, it could enjoy a credit in a programme's end titles. But, mostly, as with the Galaxy ad, its work has gone unnoticed except by industry insiders.

However, Framestore was thrust into the limelight in 2014 when Tim Webber, the company's VFX supervisor, won the Academy Award for Best Visual Effects for the company's work on Alfonso Cuarón's *Gravity*. In the film's spacewalk scenes, which make up most of the film, the only non digital elements on screen are the heads of Sandra Bullock and George Clooney. Everything else, from their spacesuits and jet packs, through the tools they use and control panels they operate, have never existed except as 1s and 0s on Framestore's computers. More than 80 per cent of the film is computer generated imagery (CGI), yet the film appears to have been shot in a physical environment. It's hard to believe that Bullock and Clooney are not crashing into solid matter.

As Duncan Kenworthy, producer of *Four Weddings and a Funeral*, *Notting Hill* and *Love Actually*, who has worked with the company on and off for the past 20 years, says. “Framestore is in the business of making the unreal real.”

Founded in 1986, with a staff of four, Framestore quickly built a reputation in the advertising world for technically impressive computer graphics. In 1996, however, it was approached by Kenworthy to work on a TV adaptation of *Gulliver's Travels*, in which Ted Danson, filmed against a blue screen, would be inserted into the imagined world.

Layering (or “composting”) one image into another has been used in film-making since the beginning of the 20th century. There are many ways to do it, from double printing a piece of film (“matting”) to shooting a scene with back projection. But today, most composting is done digitally, filmed against a blue (or green) screen, and replacing every blue (or green) pixel in a shot with another image.

“The problem was the shadows,” says Webber, 49, who worked on the series with Bartlett. “The superimposed character didn't cast the right shadows on to their environment. So what we did was develop a way of also lifting the shadows and incorporating them into the scene.” The result, even 20 years on, is impressive.

Gulliver's Travels was followed in 1999 by *Walking With Dinosaurs*, a BBC six-parter in which CGI dinosaurs feed, fight and reproduce in an equally realistic (real-world and CGI) environment. *Dinosaurs* allowed Webber to build on *Gulliver*, especially when it came to how the superimposed character interacted with the environment into which they were inserted.

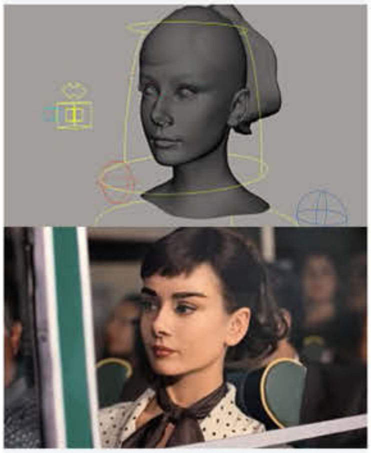
“You could make things like leaves move as they pushed past,” he says, “or dust comes up off their feet, which made it all look more believable.”

Dinosaurs also gave Framestore a way to explore creating creatures in CGI – everything that appeared on screen had to be built and brought to life digitally. And, most importantly of all, both it and *Gulliver* gave Webber a breakthrough he had long hoped for: a move into long-form storytelling.

“It got us into a whole stream of work that was different from the short-form commercials,” Webber says. “*Gulliver's Travels* involved something like 750 shots, which, for anything back then, was a huge number.”

Television miniseries (*Merlin* in 1998, *Alice in Wonderland* in 1998, *Arabian Nights* in 2000) followed and, in 2002, after a merger with The Computer Film Company, which had been using similar approaches, Framestore started work on the *Harry Potter* films, a relationship that would last until the final movie in 2011. The company was in the movie business.

Opposite page: Tim Webber, director of VFX. He was VFX supervisor for *Gravity*, for which his team won a Bafta for Special Visual Effects, and an Academy Award for Best Achievement in Visual Effects. Other films he has worked on include the *Harry Potter* series, Spike Jonze's *Where the Wild Things Are*, Christopher Nolan's *The Dark Knight*, and James Cameron's *Avatar*



Right: a 3D model of Audrey Hepburn's head. It was initially built using scans of a similar-looking actress, whose face was carefully tracked during the live-action shoot. Later, a Hepburn layer, created from scans from the actress's entire film catalogue and available stills, was applied and animated

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In a sense, Webber and his team have, at every stage, been riding the wave of technological advances that has taken place over the past two decades.

"When we started there was really very little CGI work in film," he says, "because computers couldn't handle the huge amount of data that was needed. You need a higher resolution to go on the big screen and there were just too many pixels to deal with." But they were also careful to build a reputation above simply good use of technology.

"The challenge is about using the technology," Webber says, "pushing the technology, but always as part of a creative innovation. You can't have one without the other. Well, you can, but it's not successful."

Kenworthy agrees. "Then and now their knowledge of technology was very important," he says, "but it was only a part. You take it as a given that they know everything that the most up-to-date technology is capable of. The skill is the way they work with it – the creation of a reality that doesn't exist."

Like real-world film-making, CGI is about building sets, lighting them, filling them with actors and recording the light that bounces back off them into the lens of a camera. The difference is that CGI exists entirely as a series of functions, algorithms and outputs in the processor and memory of (often many) computers. Framestore's software R&D department is on the fourth floor of a nondescript block in a mews just north of London's Oxford Street. Better lit and with a higher average age than the company's darkened animators' studios in Soho – where black T-shirts appear to be standard work uniform and, when WIRED visited, there was the faint smell of curry and sci-fi-nerd sweat in the air – R&D is run by Martin Preston, an affable 40-year-old software engineer who has been with the company since 2007. Preston and his team are essentially hackers, (though they laugh a little uncertainly when WIRED suggests that) modifying standard CGI packages such as Maya (used for creating sets, objects and characters) and Nuke and Flame (used for composting) to meet the more elaborate requirements of Framestore's ongoing projects. The company typically works on about 50 projects at any one time.

Although all three packages are feature-rich – "ready made for a small company to do a spinning logo or something like that", says Preston – achieving the kind of complexity that Framestore is known for requires modding and some cunning workarounds, provided by Preston's department in the form of C++ plug-ins, sometimes running to 200,000 lines of code. It is these technical patches, fiercely guarded from competitors (getting to Preston's office involves two locked doors and a lift, all of which can only be operated by security card), that give Framestore its edge.

"Our job," he says, "is to anticipate what's going to be required in the next project we do and to write code to make the artists' life easier."

Since its academic and mainframe origins in the 60s and 70s, most CGI animation has been cartoony and unrealistic, and for a good reason: it's extremely hard to recreate the real world in digital form. Predicting how cloth or fire will move in the wind, how water flows over pebbles or how fur, hair or skin reflect light are huge challenges involving virtually limitless variables. Artists have avoided them by dressing characters in tight clothes or giving them firmly moussed coifs. But, in the past 15 years or so, the industry has been solving many of these problems through the application of clever software and increasingly powerful processors. However, realistic depictions of elements such as human skin remains an enormous challenge – but even small advances made by the likes of Preston can give an advantage.

Take, for example, moving water. For a recent project, Framestore was asked to inundate a major European city with a flood. The streets and buildings are easy to build as CGI, but making realistic CGI water is extremely difficult.

"Audiences expect more now," Preston says. "So animators have to understand more deeply how fluids work, and we write the code to help them do that."

Below: Martin Preston, who joined Framestore from Weta Digital in New Zealand. His team's custom software plug-ins were used in the *Harry Potter* films' effects

Right: Sandra Bullock in a scene from *Gravity*. Her head is the only non-digital element in the image – it was filmed inside a two-million-LED light box. Everything else, including the spacesuit, was created digitally

The code itself was written by Preston's colleague, Michael Blain.

"An artist," he says "can build a receptacle, fill it with a fluid and throw something into it, and the plug-in will make the fluid flow and splash in a realistic way. That means they can stop worrying about whether it looks real or not and concentrate on the drama of the scene. Maybe this wave needs to be bigger, or arrive at a certain point more quickly, so the initial trigger perhaps needs to have more force."

Fluid dynamics involve a huge number of data points, especially when you are flooding a major city, but even that challenge pales into insignificance compared to the data processing required to get the movement of light correct, a set of calculations known as rendering.

At almost the final stage of a CGI animation, characters and scenery – often until this point little more than wireframe skeletons or very basic figures – are dressed in their outer "skin" and the complex procedure of calculating how light would reflect off them begins. Using a program called a shader, animators are able to see and adjust how the light they have set up in their scene colours the objects they have placed there (or more specifically how that light bounces off those objects into the virtual camera).

Shaders are continually being refined, not only as the industry as a whole understands the complexities of how light reflects off the likes of hair, fur and skin, for example, but also because good shaders make good CGI.

"In many ways, shaders define our product," Preston says, "the bit we hand over to the film studios, the bit people see."

Rendering requires a huge amount of computation and Framestore maintains ultra-high-bandwidth (10-20Gbps) pipes to very large server arrays, mostly in London's Docklands, which are able to crunch the numbers. Latency is low – a packet can travel from an artist's workstation in Soho to the Docklands and back again in about 0.1 milliseconds – but rendering complex scenes can still take hours or even days to complete due to the large amount of data involved.

'The challenge is about pushing the technology, but as part of a creative innovation'

A three- to four-second explosion can comprise as much as 2TB of information and, as Preston's colleague Mark Hills points out, much of a project's cost can come in terms of energy use and cooling the servers themselves.

Animation also places huge demands on hardware. "We have something in the order of petabytes of storage available to us," Hills says. "But what catches the vendors out when they are pitching to us is the pressure we put on those drives, the access speeds we need. During rendering there's a huge amount of information being churned all at once."

Preston laughs in agreement: "You have a massive file pushing in a way that looks like a denial of service attack."

The better the rendering, the more real the final product will look – and "real" is a word that comes up a lot in conversations at Framestore. Almost everyone will talk about the quest for verisimilitude at some point or other, whether it's in the context of a cleverly stitched together composite in a 30-second ad or the long shots of a film such as *Gravity*. And nowhere is the challenge of "real" more palpable than in creating CGI humans – and especially CGI human faces.

As Webber explains, the problem with humans is threefold. First, we (viewers) *know* faces.

"We spend a lot of time [in real life] looking at faces," he says. "And unconsciously we can see that something is wrong, even if we don't know why. The subconscious mind is incredibly skilled at analysing the human face and working out if it is happy, sad, ill, lying... So if there is something that's just wrong, it will spot it immediately."

Secondly, faces themselves are hugely complex. An array of 43 elaborately interconnected muscles can produce an almost infinite range of expressions that, consciously or unconsciously, we are alert to. This is why it is easy to tell if someone is unhappy even if they are smiling. And this range of expressions seems to be a core part of a person's identity.

"We're constantly looking at and interpreting tiny movements in someone's face and understanding what they mean," Bartlett says. "We're so familiar with them that it makes this a very thorny subject. It's something where, so easily, you can go, 'I don't know *why* it doesn't look right, but it doesn't look right.' With faces you just *know*."

What's more, it seems, we all move our faces in a unique way. Early iterations of Hepburn's face in the Galaxy ad, even though they looked exactly like existing images of Hepburn from her early days, became unconvincing as soon as they were made to move.

Right: Rocket Raccoon, from 2014's *Guardians of the Galaxy*. Framestore led the "look" development of this character. Each one of Rocket's hairs has been simulated to behave and react to neighbouring hairs (events called "collisions"), and to the environment. The aim was to balance naturalism with cartoonishness

"Basically they looked like the [lookalike] actor we had employed for the live shoot," Bartlett says.

Finally, there is the problem of depicting skin. Skin reflects light in an unusual way. Some photons bounce straight back off the surface, but others penetrate the epidermis, scattering sideways through the skin's lower layers and exiting somewhere else. This "subsurface scattering" is still not entirely understood in the physical world (materials such as marble, shells and wax do the same) and it is hard to synthesise digitally, which is why many CGI humans' skin seems plasticky or just odd.

Framestore's skill with subsurface scattering (and, in the final version, Galaxy's Hepburn looks very much the genuine article) comes mainly from work the company did on Cuarón's previous film, *Children of Men* (2006). Cuarón wanted a key character to give birth on screen – not in the usual long-shot/crying sound/actor-holding-up-a-doll way, but in all its very human detail.

"Obviously," says Webber, wryly, "it was going to be hard to film this live. Apart from anything else it wouldn't have been easy to find a pregnant actress whose schedule fitted that of the film. So the decision was made to create a CGI baby and animate its birth."

There were many challenges, he says. "You were creating something that had to be believably human. People had done CGI humans before, but not where they had to feel real. It's different if it's a fantasy movie, for example. You can accept they are not real. This was not a fantasy movie and it had to feel absolutely convincing." Added to this, the shot, as is Cuarón's trademark, was long, giving plenty of opportunities for the magic to be ruined. And, of course, most of what viewers would see would be skin.

"Getting the movement right was very important," Webber says, "but it was with *Children of Men* that I think we really cracked subsurface scattering. The scene is shot in quite

'Simulating zero gravity is unbelievably difficult – way harder than you realise'

Right: William Bartlett, creative director at Framestore. He joined in 1995; his work includes *Skyfall*'s animated opening titles

Left: *Gulliver's Travels*, 1996 – 450 effects shots. *Walking with Dinosaurs*, 1999 – won a Bafta Innovation Award. *Superman Returns*, 2006 – first Academy Award nomination for Visual Effects. *The Tale of Despereaux*, 2008 – the firm's first feature-length animation. *The Golden Compass*, 2007 – won Bafta and Academy Awards for effects in 2008. *Avatar*, 2009 – Framestore was the only UK effects firm to contribute. *The Dark Knight*, 2008 – Bafta and Academy Award nominations for special effects. *Harry Potter and the Deathly Hallows*, 2010 – Bafta and Academy Award nominations for special effects. *Dracula Untold*, 2014 – all effects, including bats

a low light, a single paraffin lamp, and that helped a lot, of course. But it was also a four-and-a-half-minute shot which is a lot of time for a viewer to see the joins. Yet I think we did it. I think it was the first time people came out of the cinema and thought, 'that was a real baby.'"

Similarly, viewers have been coming out of *Gravity* feeling that they witnessed something that was shot in space. (Buzz Aldrin said he was "very, very impressed" by the film.) Yet almost everything was filmed inside a two-million-LED light box, about ten cubic metres, which the company built at Pinewood Studios outside London.

"Space is zero gravity, and simulating zero gravity is unbelievably difficult – way harder than you realise," Webber says. "There is no up and down, and things like skin and clothes don't hang or crease like they do on Earth. Even when we were just filming their faces, if they lean over you start to see a strain on the neck because [on Earth] there is gravity, and that won't do. Every tiny little thing you do is a challenge."

The light box allowed Cuarón to keep his actors relatively upright (avoiding gravity-induced sagging) while the "set" – CGI objects pixellated into the LEDs – and the (actual) camera, on a robot arm, moved around them, correctly lighting their faces and creating what, in the end product, is a powerful sense of movement (especially in the 3D version).

Meanwhile on the CGI side, Webber had to untrain something that is virtually hardwired in good animators: a sense of weight.

"Weight is a big part of what animators learn when they are training," he says. "It's almost in their bones. But in space there is no weight and we had make them think again. Objects in space behave oddly. Once something starts moving, for example, it doesn't stop until it hits something else, as there is no air resistance. This is something very alien to us on Earth."

As part of his research, Webber went up in Nasa's "vomit comet" to experience weightlessness first hand. ("I didn't vomit," he says. "Though others did.") And he spoke to astronauts about their experience on the International Space Station.

"They were fascinating," he says. "One of the astronauts said that she could take a single hair, use it to push herself off one wall of the ISS and she wouldn't stop until she reached the other end. All of this we had to replicate in the world we built for *Gravity*."

Webber likes to say he is not led by the capabilities of technology. "I prefer to take on a project, and then see how we can use technology to respond to it creatively," he says. But 5,500km away, in Framestore's New York offices, Mike Woods is taking the opposite tack, experimenting with new tech and seeing if he can find a client who is risk-friendly enough to take it on.

Although he has been in the company for almost as long – he joined Framestore in 1996 – at 40, Woods is younger than most of the veterans. He cut his teeth mashing up home-produced videos and uploading them to the web, and, he says, he is "always on the road with new things. We create things internally, make a prototype and take it out to sell to clients."

One example is the Oculus Rift, which Woods got his hands on at a very early stage and used to develop a *Game of Thrones* VR experience for this year's SXSW. Ten thousand people used the installation in five days.

"The hardware breakthrough was the affordability of the device," he says. "Basically it's just a smartphone in a ski mask. And the 4D was also a real help." (Woods used a wind machine and a Rumble Pak to create a multisensory experience.) "But the real strength came from the work we did on real-time rendering."

Photorealistic real-time rendering requires massive processing power, usually in a single computer, constantly recalculating the way light reflects off objects' surfaces as they are moved around by users. Games consoles use powerful graphics processing units to do the maths (which is why console games are often much more realistic than those on a PC). Woods's breakthrough was to integrate a similar real-time rendering engine into Framestore's traditional CGI process.

"People still use the same publishing tools [to create objects, light them and move them around]," he says. "But in the end we put in a real-time engine, which opens up the way to live virtual reality of a very high quality."

The results aren't perfect. "Asking one machine to do something to the same quality as a huge server farm is a big ask," he says. "But we're getting closer. Textures and things like mist and water are great. Human and animal animation [are next]. If you look at, say, the PS4 trailer for *Watch Dogs*, it's really close to perfection. Take the humans out and it's very filmic."

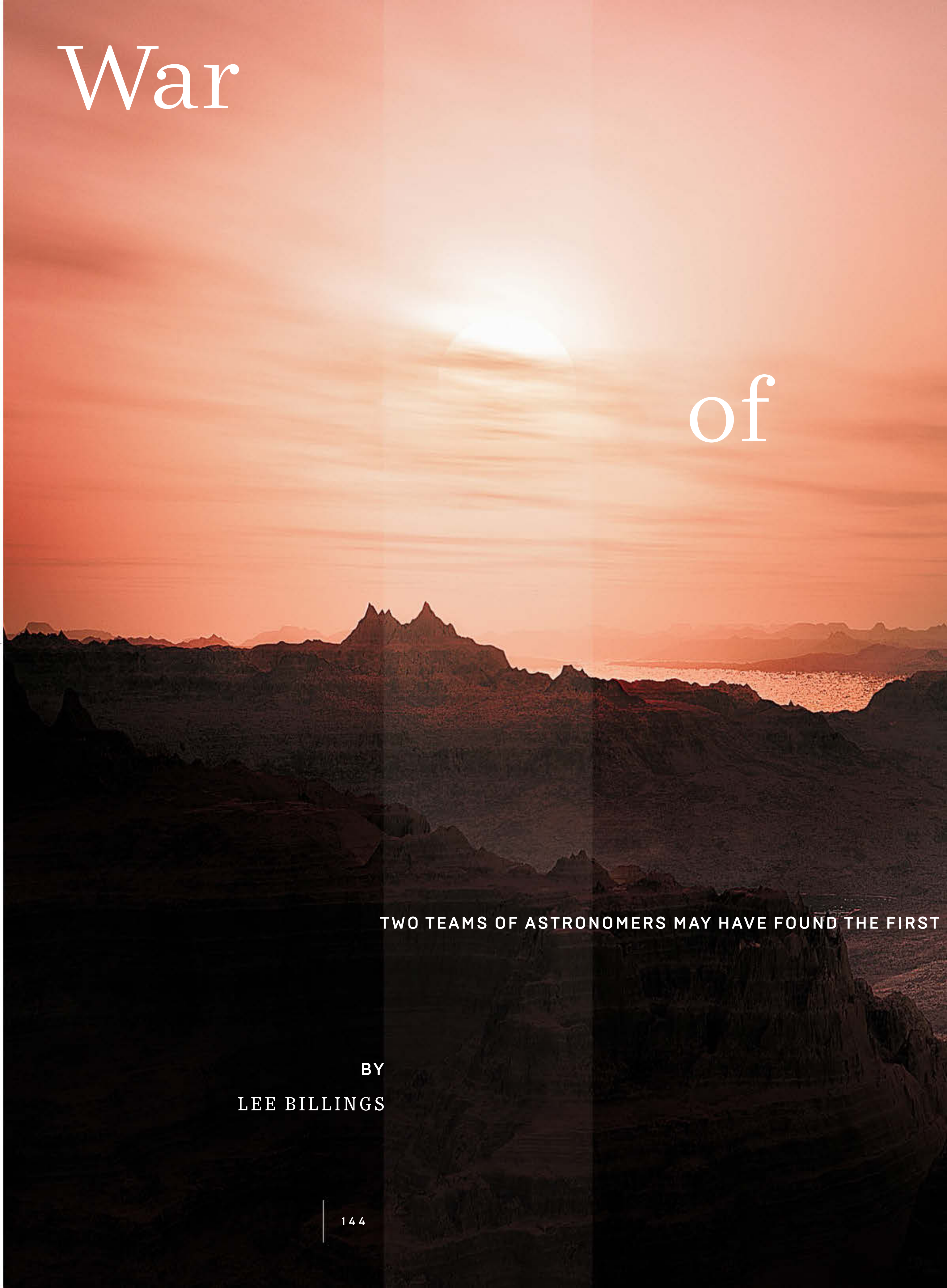
It's quite possible, of course, that no company will ever crack what could be called the Turing test of CGI, a computer-generated human who acts, moves and emotes like a real person.

"We're a long way from pushing a button and having Audrey Hepburn selling beer," Preston says. "Right now she doesn't even open her mouth. Besides, the artist will still be central to the process. We have e-books, for example, but we still need authors."

And this is probably not the real aim of anyone in Framestore, where human creativity is valued as highly as tech savviness. The company thrives on responding to creative challenges using a mix of science, technology, some sleight of hand and a lot of old-fashioned storytelling. (Webber's next goal is to direct a film himself. "I have some ideas in development," he says.) And should the time come when computers can do creative work as well as people, you get the feeling that Webber, Bartlett and their colleagues would be just a little disappointed.

"If that happens," says Woods, "we can make a holodeck and I can walk into the sunset knowing there is nothing more to do. You could walk into an office and be given a headset and be anywhere, and you wouldn't even know you were wearing a headset. Luckily, I think that is a long way off."

David Baker edited The WIRED World in 2015*, on sale now, £6.99*



War of

TWO TEAMS OF ASTRONOMERS MAY HAVE FOUND THE FIRST

BY

LEE BILLINGS

the

EARTH-LIKE PLANET IN OUTER SPACE. SO WHO TRULY DISCOVERED GLIESE 667Cc?

worlds

No one knows what the planet Gliese 667Cc looks like. We know that it is about 22 light-years from Earth, a journey of lifetimes upon lifetimes. But no one can say whether it is a world like ours, with oceans and life, cities and single-malt Scotch. Only a hint of a to-and-fro oscillation in the star it orbits, detectable by Earth's most sensitive telescopes and spectrographs, lets astronomers say the planet exists at all. The planet is bigger than our world, perhaps made of rocks instead of gas, and within its star's "habitable zone" – at a Goldilocks distance that ensures enough starlight to make liquid water possible, but not so much as to nuke the planet clean. That's enough to fill the scientists who hunt for worlds outside our own solar system – so-called exoplanets – with wonder. Gliese 667Cc is, if not a sibling to our world, at least a cousin out there amid the stars. No one knows if it is a place where we humans could someday live, breathe and watch triple sunsets. No one knows whether barely imagined natives are right now pointing their most sensitive and far-seeing technology at Earth, wondering the same things. Yet regardless, to be the person who found Gliese 667Cc is to be the person who changes the quest for life beyond our world, to be remembered as long as humans exist to remember – by the light of the Sun or a distant, unknown star. Which is a problem. Because another thing no one knows about Gliese 667Cc is who should get credit for discovering it.

Gliese 667Cc is at the centre of an epic controversy – a fight over the validity of data, the nature of scientific discovery and the ever-important question of who got there first.

IN LATE 1995, SWISS ASTRONOMER Michel Mayor and his student Didier Queloz found 51 Pegasi b, the first known exoplanet orbiting a Sun-like star. It was orbiting far too close to its sun to allow the formation of water, but the discovery made Mayor's European team world-famous anyway.

Soon, though, they lost their lead in the planet-hunting race to a pair of American researchers, Geoff Marcy and Paul Butler. The two men had been looking for exoplanets for almost a decade; they bagged their first two worlds a couple of months after Mayor's announcement.

The two teams evolved into fiercely competitive dynasties, fighting to have the most – and most tantalising – worlds to their names. Their rivalry was good for science; within a decade, each had found in the order of a hundred planets around a wide variety of stars. Soon the hunt narrowed to a bigger prize. The teams went searching for smaller, rocky planets they could crown "Earth-like."

Most planet hunters aren't looking for exoplanets, per se. Those worlds are too small and dim to easily see. They're looking instead for tell-tale shifts in the light of a star, "wobbles" in its spectral identity caused by the gravitational pull of an unseen orbiting exoplanet. When that force tugs a star toward Earth, the Doppler effect ever so slightly compresses the waves of light it emits, shifting them toward the blue end of the spectrum. When the star moves away from Earth, its waves of starlight stretch to reach us, shifting toward the red. You can't see those shifts with the naked eye. Only a spectrograph can, and the more stable and precise it is, the smaller the wobbles – and the planets – you can find.

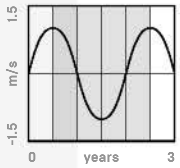
By late 2003 the European team had a very precise instrument, the High Accuracy Radial velocity Planet Searcher, or HARPS. Mounted to a 3.6-metre telescope on a mountaintop in Chile, HARPS could detect wobbles of less than a metre per second. (Earth moves the Sun just a tenth that amount.) The Americans had to make do with an older instrument called the High Resolution Echelle Spectrometer, or HIRES – less precise, but paired with a more powerful telescope.

As the two teams continued to fight for pre-eminence, trouble was brewing among the Americans. Marcy, a natural showman as well as a brilliant scientist, regularly appeared on magazine covers, newspaper front pages, and even David Letterman's late-night talk show. His far more taciturn partner, Butler, preferred the gritty tasks of refining data pipelines and calibration techniques. Having devoted years of their lives to the planet-hunting cause, Butler and another member of the team, Marcy's PhD adviser, Steve Vogt (the mastermind behind HIRES), began to feel marginalised and diminished by Marcy's growing fame. The relationships hit a low in 2005, when Marcy split a $1 million (£600,000) award with their archrival, Mayor. Marcy credited Butler and Vogt in his acceptance speech and donated most of the money to his home institutions, the University of California and San Francisco State University, but the damage was done. Two years later, the relationship disintegrated. Butler and Vogt formed their own splinter group; Butler and Marcy have barely spoken since.

It was a risky move. HARPS and HIRES remained the best planet-hunting spectrographs available, and Butler and Vogt now lacked easy access to fresh data from either one. The American dynasty was shattered, and Marcy was forced to find new collaborators. Meanwhile, the ever-expanding European team continued to wring planets from HARPS even though Mayor had formally retired in 2007. The search for Earth 2.0, long seen as a struggle between two teams, became a more crowded and open contest.

Then a seeming breakthrough: in the spring of 2007, the Europeans announced that they'd spotted a potentially habitable world, Gliese 581d[1]. It was a blockbuster – a "super-Earth" – on the outer edge of the habitable zone, eight times more massive than our own world.

Three years later, in 2010, Butler and Vogt scored their own big find around the same star – Gliese 581g. It was smack in the centre of the habitable zone and only three or four times the bulk of Earth, so idyllic-seeming that Vogt poetically called it Zarmina's World, after his wife, and said he thought the chances for life there were "100 per cent". Butler beamed too, in his own subdued way, saying "the planet is the right distance from the star to have water and the right mass to hold an atmosphere." They had beaten Marcy, laid



STELLAR WOBBLE

The spectral fluctuations of a star with an exoplanet create a sine wave

ILLUSTRATION (OPENING SPREAD): ESO/L CALÇADA. (THIS SPREAD): LYNETTE COOK/NASA; JOE MCKENDRY

[1] Astronomer Wilhelm Gliese catalogued hundreds of stars in the 50s. The lower-case letter marks the order in which astronomers discovered the planets orbiting a star

some claim to the first potentially Earth-like world, and bested their European competitors.

But, to a chorus of sceptics, Zarmina's World simply seemed too good to be true. The European group said the signals the Americans had seen were too weak to be taken seriously. The fight was getting ugly; entire worlds were at stake.

PLOTTED ON A COMPUTER screen, a stellar wobble caused by a single planet looks like a sine wave, though real measurements are rarely so clear. A centimetres-per-second wobble in a million-kilometer-wide ball of seething, roiling plasma isn't exactly a bright beacon across light-years. Spotting it takes hundreds to thousands of observations, spanning years, and even then it registers as a fractional offset of a single pixel in a detector. Sometimes a signal in one state-of-the-art spectrograph will fail to manifest in another. Researchers can chase promising blips for years, only to see their planetary dreams evaporate. Finding a stellar wobble caused by a habitable world requires a volatile mix of scientific acumen and slow-simmering personal obsession.

A Spanish astronomer named Guillem Anglada-Escudé certainly meets that description. Now a lecturer at Queen Mary University in London, he began working with the American breakaways Butler (a friend and collaborator) and Vogt not long after they announced Gliese 581g.

Today, Anglada-Escudé's name is on the books next to between 20 and 30 exoplanets, many found by scraping public archives in search of weak, borderline wobbles. The European Southern Observatory, which funds HARPS, mandates that the spectrograph's overlords release its data after a proprietary period of a year or two. That gives other researchers access to high-quality observations and potential discoveries that the HARPS team might have missed. Scavenging scraps from the European table, it turns out, can be almost as worthwhile as being invited to the meal.

In the summer of 2011, Anglada-Escudé was a 32-year-old post-doc at the end of a fellowship, looking for a steady research position in academia. With Butler's help he had developed alternative analytic techniques that he used to scour public HARPS data.

In fact, Anglada-Escudé argued that his approach treated planetary data sets more thoroughly and efficiently, harvesting more significant signals from the noise.

One late night that August, he picked a new target: nearly 150 observations of a star called Gliese 667C[2] taken by the HARPS team between 2004 and 2008. He sat before his laptop in a darkened room, waiting impatiently as his custom software slowly crunched through possible physically stable configurations of planets within the data.

The first wobble to appear suggested a world in a seven-day orbit – the faster the orbit, the closer to the star the planet must be. A week-long year is about enough time to get roasted to an inhospitable cinder – and anyway, the HARPS team had announced that one in 2009, as the planet Gliese 667Cb. But Anglada-Escudé spied what looked suspiciously like structure in the residuals of the stellar sine wave snaking across his screen. He ran his software again and another signal emerged, a strong oscillation with a 91-day period – possibly a planet, possibly a pulsation related to the estimated 105-day rotation period of the star itself.

He decided to try once more before bed, nulling the seven- and 91-day signals. When the final fit was complete, he stared for a long moment at the results on his laptop's glowing screen, then smoked a cigarette to calm his fraying nerves. The software had uncovered what looked to be another planet. But this one had a 28-day orbit, in Gliese 667C's habitable zone. It looked rocky too, because it was just over four times the mass of Earth. This was what came to be known as Gliese 667Cc. If the data held, it would be the third Earth-like world ever discovered. "It was very strange," Anglada-Escudé told me in 2012, when I was reporting the story of Gliese 667Cc for my book, *Five Billion Years of Solitude*, "to find an unpublished, unclaimed, potentially habitable planet in a three-year-old public data set." Yet there it was.

Anglada-Escudé took his numbers to his mentors, Butler and Vogt. Butler took 21 new measurements of Gliese 667C with the Carnegie Planet Finder Spectrograph in Chile, and Vogt retrieved 20 more measurements

GUILLEM ANGLADA-ESCUDÉ

He claims he discovered Gliese 667Cc in archive data

[2] The capital C indicates a trinary system, with A and B stars

> AS ROBERTSON REVIEWED THE DATA, PLANETS STARTED DISAPPEARING INTO THE STATISTICAL NOISE. THE FIRST EARTH-LIKE EXOPLANET WAS NOW GLIESE 667Cc

from archived HIRES data. It all only bolstered the finding, and the team began drafting a discovery paper.

But Anglada-Escudé wanted to be absolutely certain the signal was genuine. The best plan: get new data from HARPS, the European spectrograph. Since Germany was a member of the consortium that funds the instrument, and Anglada-Escudé was at the time working at a German institution, he could apply to use it. Worried it would tip off the European team, Butler and Vogt cautioned against it. But Anglada-Escudé wanted those numbers to cement the discovery. On September 28, 2011, he submitted a proposal for 20 nights on HARPS with Gliese 667C on his target list and mentioned the existence of a 28-day signal detected in its vicinity.

In the following weeks, Anglada-Escudé monitored his personal website for visits by members of the HARPS review committee. He figured if they were checking his credentials, it meant they were reviewing his proposal. In mid-November he saw a spike in traffic from Garching, Germany, where the review committee was based, as well as from other cities around Europe with HARPS team members.

And then his HARPS proposal was rejected.

About two months after Anglada-Escudé's initial application, the HARPS researchers uploaded a paper to a public online repository of preprints – unreviewed but otherwise rigorous research reports. The preprint summarised HARPS observations of red dwarf stars from 2003 to 2009, and the team had already submitted it to a prominent journal. Grenoble, France-based Xavier Bonfils – head of the HARPS campaign to find planets around red dwarf stars[3] – was its lead author. Within its 77 pages, one paragraph and a short entry in a data table discussed the team's detection of a super-Earth in a 28-day orbit around Gliese 667C, stating that a more detailed discovery paper was in preparation.

Vogt was first to see the HARPS team's preprint. He sent a terse email to Butler and Anglada-Escudé: "We've been scooped". "I was very upset," Anglada-Escudé said. "So I reread the preprint again and started cataloguing strange things." He found what he believed to be a smoking gun: Gliese 667Cc's orbital period was correctly included as 28 days, but another datum for the planet – separation from its star – erroneously matched an orbit of about 91 days. The entry, it occurred to Anglada-Escudé, might at one time have concerned a different signal, before perhaps being hastily changed. He started to wonder if the HARPS team had seen his proposal and quashed it so they could take credit for the blockbuster Earth-like planet they had overlooked. "It could have all been a coincidence," he said. "But I couldn't help feeling suspicious."

Anglada-Escudé pushed harder to claim what he felt was rightfully his. He and his collaborators wrote their discovery paper and submitted it to *Astrophysical Journal Letters*, an influential publication that reviewed and published it before the HARPS team's paper went to press.

The Europeans cried foul. They got a paper into *Astronomy & Astrophysics* and began a modest PR campaign to strengthen their case as Gliese 667Cc's true discoverers.

That June, Bonfils and Anglada-Escudé attended an astronomy conference in Barcelona, and the two men met privately to hash out their differences. Over espresso in a café, they talked quietly for an hour. But as they conversed, their words and attitudes hardened. Neither man would back down from claiming to have found the faraway world first.

XAVIER BONFILS

His European team says it found Gliese 667Cc first

THE FIGHT WOULD BE little more than an academic footnote if it weren't for an up-and-coming astronomer, Paul Robertson, a post-doc at Penn State University. His contribution began, as so many momentous discoveries do, with an expletive: "Oh, shit".

Robertson was sitting at his computer on a chilly afternoon this past February, looking at data from the star the Americans and Europeans first started fighting about, Gliese 581. He was using specialised analytical techniques to try to correlate the magnetic activity of the star to the supposed wobbles, all in an attempt to settle once and for all whether Gliese 581g – Zarmina's World – was real or just noise. As he delved into the data, the wobble from Gliese 581g indeed dissipated into static, falling far below the threshold of statistical significance. It seemed the American team had only seen a ghost. The second ever Earth-like exoplanet would have to be crossed off the star charts.

But the plots scrolling across Robertson's screen revealed something else: the Europeans' find, Gliese 581d, long considered an unimpeachable discovery and the first plausibly Earth-like planet ever found, vanished as well.

There was no avoiding it. Robertson published a paper explaining that some of Earth's foremost astronomers had gotten it wrong. "Busting other people's planets was never really my intention – I'm more interested in finding them," Robertson says. But even though he hadn't asked for a reputation as a ruthless destroyer of

[3] Star type depends on colour and temperature. Our Sun is a yellow dwarf; Gliese 667C is a cool red dwarf

worlds, Robertson couldn't shake the feeling that more false-positive planets were out there, calling like Sirens to scuttle unsuspecting planet hunters in deep, turbulent seas of noise. With the potential Earths of Gliese 581 now dead as Alderaan, Robertson's team moved to the next world on the list: Gliese 667Cc. But even under Robertson's scrutiny, it wouldn't go away.

In other words, the planet whose discovery was so highly contested became, officially, the first potentially Earth-like world ever detected. The person who found it should be able to bask in the achievement ever after – if he can make his claim stick.

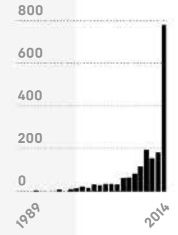
NOT LONG AFTER THE failed coffee-shop détente, I talked to an exasperated Bonfils. The whole thing was, he said, a misunderstanding, compounded by speed bumps typical of the publication process. The European team had submitted its survey for peer-reviewed publication in the spring of 2009, Bonfils explained, long before Anglada-Escudé's research. Feedback from a fellow researcher had delayed the preprint's release until late 2011. He dismissed the minor inconsistencies it contained as simple mistakes, nothing more. In his view, the most pertinent fact was that others were attempting to take credit for a discovery they had not made. "HARPS was built by our team, and the scientific programme and observations were done by our team," Bonfils said. "Most of the data reduction was already done and provided in our public data."

In other words, as Bonfils sees it, his team had already done the hard work of analysing the data. (Vogt says this is no longer true. The Europeans, he wrote in an email – not to me, but since published – process and archive data in a way that specifically makes it "not reliable by any other than HARPS team individuals." So Vogt says his team now reprocesses the public data and derives their own measurements of wobbles.)

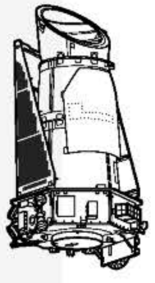
What was at stake here was more than just the discovery. It was about access to and treatment of data. "It would be a pity if the guys who made the instruments, and designed and performed the programme of observations, did not receive credit for their work," Bonfils said. "I'm a supporter of public data, but I had long feared someone would try to publish our data before us, and it has now happened. Right now this community rests on good behaviour and gentlemen's agreements." Bonfils said he senses "anger, an aggression" in Butler, Vogt, and their collaborators – including Anglada-Escudé. "You see it in their papers, in the language and accusations," Bonfils said. "I think it has become more difficult for them to get the observing time they need." And without access to the right machines, the group had no choice but to go a little rogue.

In the research community, who an astronomer believes actually discovered the planet seems to depend to some degree on which side that astronomer is closer to – the established, old-guard teams of Marcy and the HARPS superstars, or Anglada-Escudé and a few other upstarts. Meanwhile, those upstarts still unabashedly seek overlooked planets in the public data from HARPS and other instruments. As a result, the fight between Bonfils and Anglada-Escudé seethes beneath the cordial formalities of professional astronomy. Bonfils now calls Anglada-Escudé's behaviour "unethical," citing several further clashes over questionable planets drawn from HARPS data. Anglada-Escudé still believes the HARPS team is stonewalling him – a claim Bonfils says is ridiculous. "We don't have this power," he says.

In 2009, Nasa launched the Kepler space telescope on a three-and-a-half-year planet-finding mission. Chasing Earth in orbit around the Sun, Kepler looks for exoplanets by searching for worlds that "transit" across their stars as seen from our solar system, revealing themselves in silhouette. The £300-million telescope has found almost 1,000 exoplanets this way, including – as of April 2014 – an Earth-sized world called Kepler 186f, orbiting in the habitable zone of a star about 500 light-years away. That's too far off for an easy follow-up investigation. But Kepler's scientists would argue that's not really the point. Their discoveries have moved the field well past the stage where any individual planet or person holds the same allure as the heroic, obsessive world-seekers of years past. Not that long ago, the discovery of a single exoplanet was an international media sensation. In February, by contrast, the Kepler mission announced 715 new exoplanets. Outside the astronomy community, nobody really cared.



Number of exoplanets discovered



KEPLER SPACE TELESCOPE

In February 2014 Nasa announced it had discovered 715 new exoplanets

Kepler's results strongly suggest that planets of all types – including ones identical to Earth in their broad description – are common. The search for Earth 2.0 is, in a sense, already over, even though it has barely begun. Now astronomers want a galaxy-encompassing statistical planetary census, accounting for the profound diversity of planetary systems along the way. Such an approach doesn't focus on individual exoplanets. But it can tell you, as Kepler's rich statistics already have, that about one in five Sun-like stars should harbour an approximately Earth-sized planet in the habitable zone, placing the nearest life-friendly world somewhere within perhaps a dozen light-years of our solar system. That calculation actually comes from Geoff Marcy's group – even the central figure from planet-finding's Heroic Age has changed with the times.

Yet when it comes to discovery, being first still matters. It's built into the kind of exploration that planet hunting embodies. It comes from the same insatiable urge that drove our ancestors to climb down from the trees, then race from horizon to horizon, until they finally ran out of frontiers. Even if we have exhausted most new places to explore on Earth, our desire to discover, to make the unknown known with our names, our dreams, our stories, is inexhaustible. We call Jupiter's four largest moons Galilean because Galileo saw them first. We look to the stars because we see in them a future, and being first gives someone the power, however mystical and irrational, to make that future manifest and give it life and meaning that could echo through generations. Even if history doesn't always choose the right person.

Bonfils and Anglada-Escudé actually agree on a lot. They both think planetary data should be open. They both want more and better instruments to monitor each and every nearby sun for planet-induced tremors. They both hope for a grand space telescope that will actually see all the worlds within a hundred light-years of Earth – and anyone who lives on them. Like Robertson, they don't want to destroy other people's planets. All they want is to find new ones – faraway pale blue dots, kin to our own, pirouetting silently in a habitable zone, all tumbling together through endless night.

Lee Billings wrote Five Billion Years of Solitude*, published by Current in 2013*

ILLUSTRATION: JOE MCKENDRY; SCHRIS PHILPOT. SOURCE: EXTRASOLAR PLANETS ENCYCLOPAEDIA

Left to right: Enrique Benedicto (photo assistant), Jeanna Lee York (Stephen Hawking's PA), Marco Grob (photographer), Patricia Dowdy (Hawking's nurse), Andrew Diprose (WIRED's creative director), Eduardo Asaso Perez (photo assistant), João Medeiros (WIRED's science editor). **Centre:** Stephen Hawking (genius)

OVERHEARD IN THE WIRED OFFICE THIS MONTH

"No. Go away. Don't call back" – the agent of Dan Castellaneta, on hearing WIRED ask for permission to use Homer Simpson's voice.

"A woman who looks cool, next to a cool machine. This is good. Her shoes are weird, though."

"There's nothing I like more than butting lines. Or a nice, tight vector."

"So you do the DNA test and it *doesn't* tell you when you're going to die? How rubbish is that?"

"Of course it's important. Do you *want* your baby to get bullied by other babies?" – from a discussion on the merits of £1,000+ baby strollers.

"OK, it's 3D printed – *but what is it?*"

"It tastes like the sort of food a doll would eat" – description of gluten-free custard-cream biscuits.

"Does anyone here have an Android phone?"

"I don't know. Do I?"

"Sometimes, I wish I was working in a hut in the middle of a forest."

Want to write for WIRED? Please pitch your ideas to editorial@wired.co.uk. PRs please contact us at pr@wired.co.uk and not by phone. Feedback and thoughts about the WIRED world to rants@wired.co.uk.

REJECTED HEADLINES THIS MONTH

Foot fetish

Professional 12-inchers

I made it through the wilderness

How I learned to stop worrying and love the drones

Snow stud

THE COLOPHON

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THE WIRED INDEX

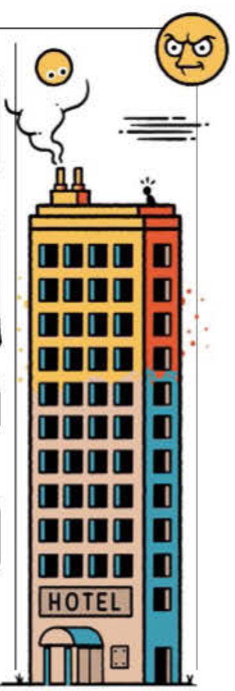
DATA CLUTTERING OUR INBOXES THIS MONTH

15%

Increase in the number of calls made by staff in call centres in the UK and the Netherlands, after their bare offices were enriched with a selection of green plants. The results were observed by Cardiff University psychologists

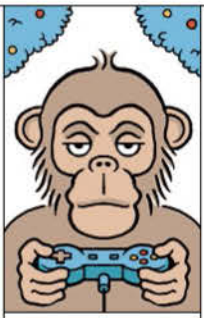
FOUR HOURS

Time taken for viruses to spread to 60 per cent of people and surfaces in offices, hotels and healthcare centres studied by the University of Arizona's Gerba Lab



350

Weight in kilograms of a female colossal squid, *Mesonychoteuthis hamiltoni*, dissected in a webcast by scientists at the Auckland University of Technology. Only two of this species have ever been caught intact



1,141,800

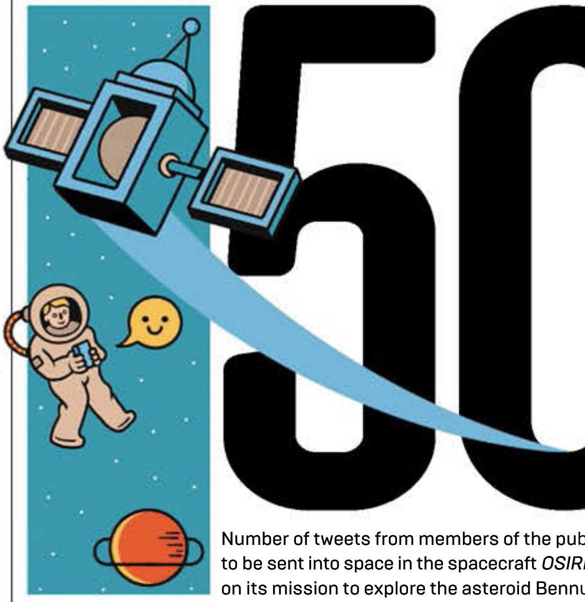
Final score in a three-hour session of *Donkey Kong* achieved by New Hampshire-based competitive gamer Robbie Lakeman in September 2014, toppling Hank Chien's four-year record of 1,138,600

0.02

Average deviation from ideal choices made by two chimpanzees pressing buttons to either match or mismatch another player's selection to gain a reward

219 million

Stars recorded in the most detailed catalogue of the Milky Way, assembled over ten years by astronomers using the super-sensitive Isaac Newton Telescope



50

Number of tweets from members of the public to be sent into space in the spacecraft *OSIRIS-REx* on its mission to explore the asteroid Bennu

122

Number of LEGO scenes recreating key events from David Foster Wallace's 1,104-page *Infinite Jest*, built by Kevin Griffith, an English professor at Ohio's Capital University, and his 11-year-old son Sebastian

0.13

Average deviation by humans in the same study

1.6 CENTS

The amount it costs the United States Mint to produce a one-cent coin

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